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A STOCHASTIC MODEL OF SOIL EROSION

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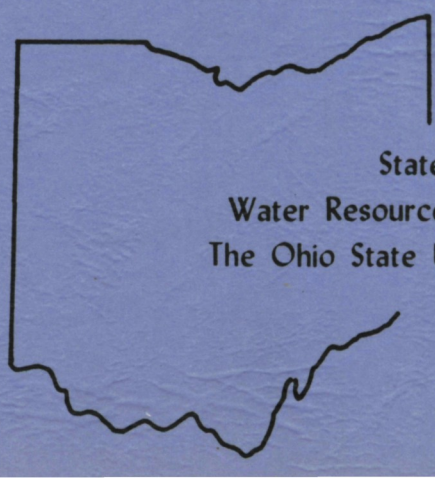

State of Ohio
Water Resources Center
The Ohio State University

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1. INTRODUCTION

1.1 Problem Statement

The removal of soil by moving water operates on the earth's surface from mass wasting on a geologic scale to small scale erosion on construction sites and slopes. The process presents important problems to engineering, agriculture and geology. While many erosion measurements have been made over the years, it is only recently that analytical expressions of the erosion process have been derived for rather simplified conditions. Because of the many factors that control erosion the study of its mechanics requires consideration of several disciplines. One way to study a complex process like erosion is to construct a mathematical model that contains as many of the controlling factors as can be handled by the computing process and then perform numerical tests that will assess the influence exerted by these factors. Then experiments can be done to study the individual factors. This report describes a first attempt at such a model and presents some of the results of simulations using this model.

The process of erosion begins when raindrops strike an inclined soil surface and detaches soil particles from larger aggregates. In the case of some cohesive soils the detached particles may themselves be composed of finer particles held together by physical-chemical forces. When the rainfall exceeds the infiltration rate, the overland flow begins and the detached soil particles are carried away. The overland flow tends to be concentrated in low areas,called rills,where erosion should also be most severe (e.q. ref. 24). Erosion during successive rainstorms deepens the rills and they become gullies. The quantity of soil eroded is clearly dependent on the topography of the eroded surface, which is composed of rills and inter-rill areas (24). Hence a realistic

erosion model should simulate the development of the eroded surface by computation of the erosion on different parts of the surface.

The random nature of the rill pattern and its contribution to the development of a drainage network was recognized by Leopold and Langbein (17), Horton (12), Scheidegger (32) and simple simulations of topographical change starting with an initial random surface have been presented by Schenck (33), Smart et al (36), and Seginer (34). On a given surface, simplified as a plane, equations of sediment transport may be used to compute the amount of erosion and various relations have been suggested by Meyer and Wischmeier (21), Foster and Meyer (6) (7), Li et al (18), and Komura (15). Smith (37) developed a numerical model that accounts for variations in slope, and rill geometry for unsteady state conditions. The equation may be solved to yield erosion in each time step. Thus, it is timely to combine the equations of erosion with the randomness of the surface topography in a model of the erosion on a sloped surface.

1.2 Objectives and Scope

The overall objective of this research is to develop a mathematical model of the progress of erosion on sloping ground. It is required that the model should be able to account for the irregular topography of the ground surface, the pattern of overland flow that is compatible with the topography, and the erosion and topographic change that results from this flow.

To attain the objective, three principal tasks were completed: (1) analysis of ground surface roughness and construction of the random surface model (2) study of sediment transport equations and construction

of the erosion model and (3) construction of the simulation model that computes the erosion and topographical changes. These models are described in Chapters 2, 3, and 4 respectively. In addition, tests were performed to evaluate the model's sensitivity to several important parameters. Limited numerical experiments were made to compare model performance with empirical results. This work is reported in Chap. 5.

The model presented here represents a first attempt and contains many simplifications out of necessity. Hence model predictions are only expected to provide order-of-magnitude estimates of the real process. Comparison of model performance with detailed experiments may be expected to identify shortcomings in the model and lead to refinements. In principle the model is not restricted to a particular scale. However, because of availability of data and the importance of erosion on construction sites and reclaimed land, we have used data from erosion plots for this work.

1.3 Acknowledgements

This research was supported by a grant from the Office of Water Research and Technology, Dept. of Interior. Most of the modeling work was done by M. E. Mossaad as his Ph.D. dissertation. The experiments on soil detachment described in Appendix A were performed by K. L. McCurdy.

The writers are grateful to professor V.T. Ricca and D.M. VanDoren Jr. for their contributions to this study.

2. SURFACE ROUGHNESS MODEL

2.1 General Considerations

The surface topography of a soil slope generally consists of a large number of humps of irregular shapes and sizes with depressions or rills, in between. When overland flow moves downslope, the water tends to concentrate in the meandering depressions, which constitute the flow paths as shown in Fig. 2.1.

A random surface model is required to generate a surface which has characteristics representative of the real surface. It is desirable that the statistical properties of the generated surface be as close as possible to those of the original surface. In addition, the numerical representation of the surface must be suitable for erosion computations. The trade off between those two conditions is the main consideration in the formulation of the random surface model.

2.2 Method of Spectral Analysis

Consider an elevation trace along any line on a slope surface, as shown in Fig. 2.2. The spacing between measurements, must be small enough to reveal the necessary details, namely, rills and humps. This profile can be considered as a continuous function, f(x), with the distance, x, as the independent variable. Fourier analysis can then be used to express this function as a sum of an infinite number of sinosiodal terms.

According to the Fourier theorem, (Bath, 2), a periodic function x(t), having a fundamental period, T, and satisfying the conditions known as Dirichlet's conditions, can be represented by an infinite Fourier series,

$$x(t) = \frac{A_o}{2} + \sum_{n=1}^{\infty} (a_n \cos n w_o t + b_n \sin n w_o t), \qquad (2.1)$$

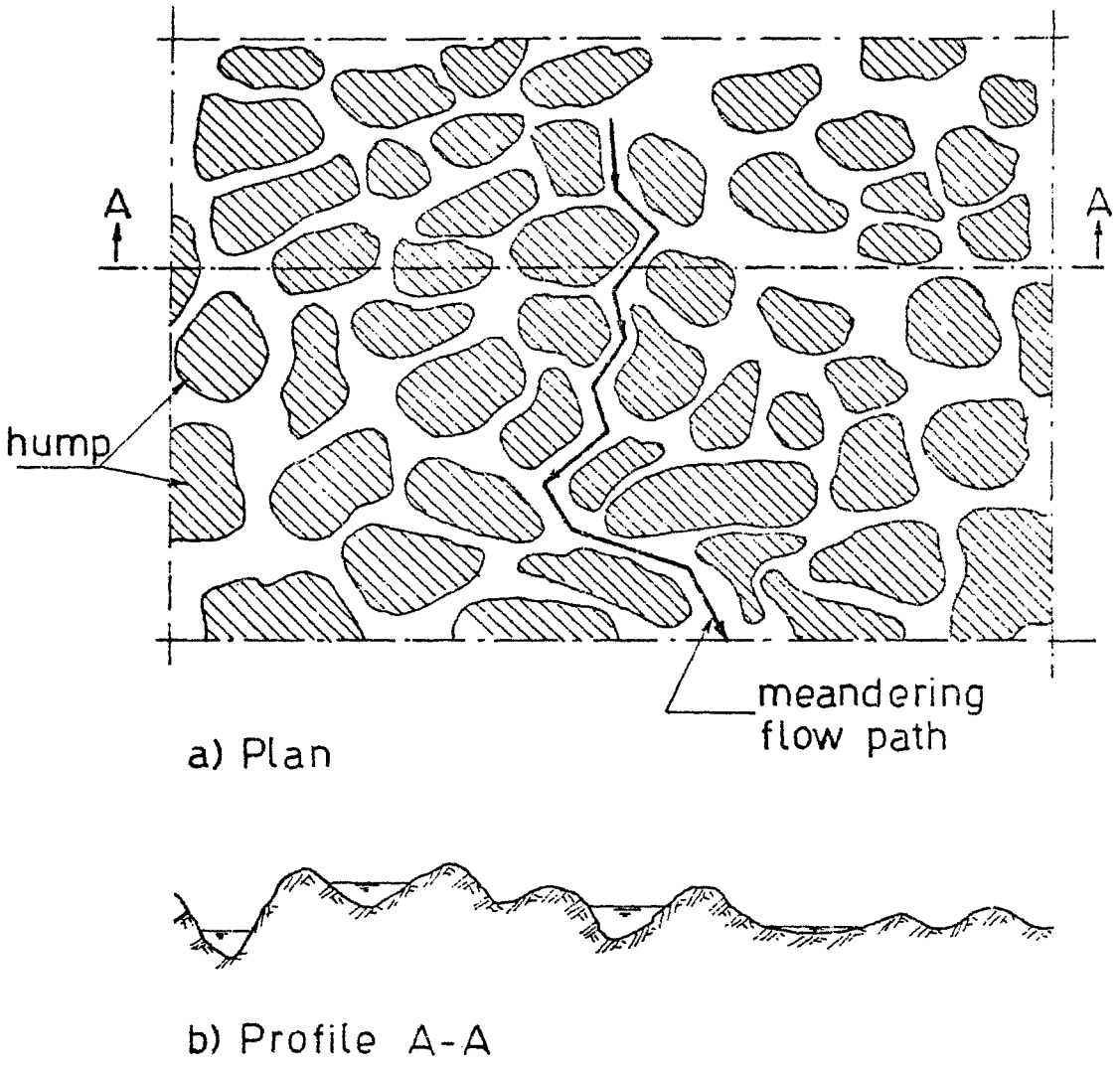

Figure 2.1 Natural Surface Roughness

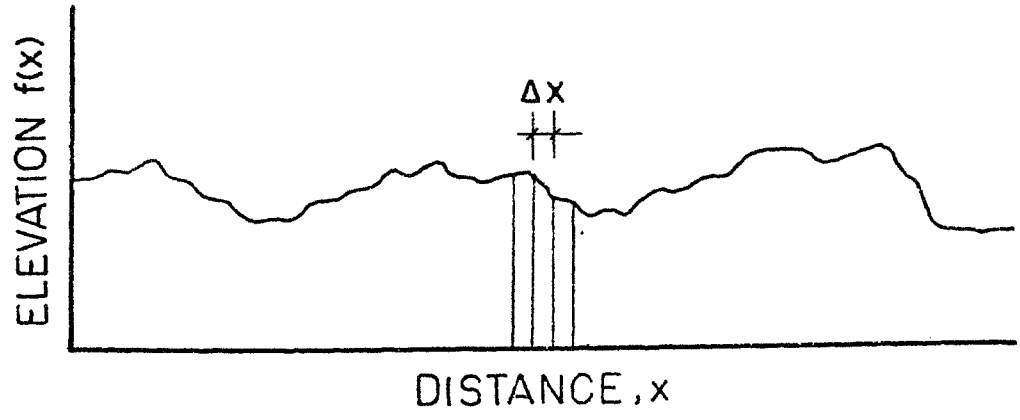

Figure 2.2 Elevation Trace

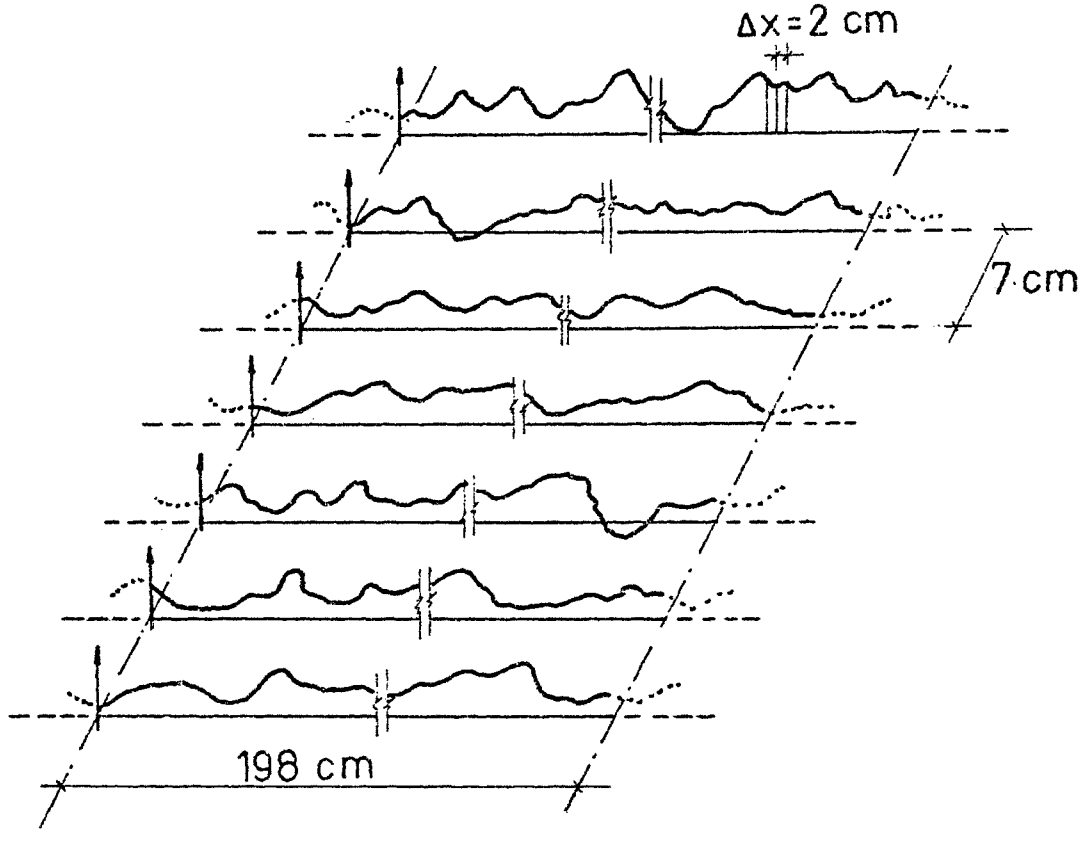

Figure 2.3 Measurement Plot

where $w_o = 2\pi/T$, is the fundamental angular frequency, a_n, and b_n are Fourier coefficients.

Thus a data record must be expressed in the form of a finite number of sinosoidal waves. Each wave has its own contribution to the total variance of the record. This contribution depends on the value of the coefficients a_n, and b_n associated with this wave. An alternative terminology for the total variance is the total power.

Field measurements of the surface roughness are usually carried out by measuring the elevation of a number of equidistant points along a certain line. A measurement plot is composed of several profiles or elevation traces.

The surface roughness as represented by the random variations of elevation with distance can be regarded as a stochastic process. Each one of the elevation traces can be taken as a realization of the same stochastic process, if the irregularity of the land surface is "homogeneous," a term introduced by Merva et al. (20). A surface is homogeneous if the nature of the irregularity does not change from location to location. This condition is usually fulfilled incases where mechanical treatment of the surface is the same at all locations.

If each elevation trace represents a realization, then the group of traces in a measurement plot is considered an ensemble (See Figure 2.3). The properties of the stochastic process are better represented in an ensemble than in a single realization. It is therefore preferable to include the whole ensemble in the spectral analysis.

The classical method of analyzing an ensemble in time domain is to compute the autocorrelation function of each realization, then the overall autocorrelation function is calculated by averaging values of autocorrelation functions at each time lag (27). In spectral analysis, however,

the spectrum of a process contains the same information given by the autocorrelation function, but in frequency domain. Accordingly, the overall spectrum of a process can be computed by averaging Fourier coefficients of the same harmonic component for all realizations, then the average harmonic components are composed together to produce the spectrum.

According to Merva et al. (20), a surface is called isotropic if the statistical properties, estimated by measurements taken along two orthogonal traces, are identical. It is clear that such a condition cannot be met in plowed surfaces, or in surfaces which have experienced considerable erosion.

When field measurements are made along parallel traces, they represent elevation variation only in one direction. When the analysis of this data is used to generate a surface, the assumption of isotropy of the surface irregularities is then implied.

It is important to mention that the method of spectral analysis can be used to study the data in two-dimensional form directly. That is, the data of all points on a plot are treated as one data record (29). In fact, Shinozuka and Jan (35) described the procedure to use two-dimensional spectral analysis in generating a random surface. The generated surface in this case would probably be a better representative of the original one, but would impose greater difficulties on the operation of erosion mechanisms. Therefore, in the present simplified model, the random surface is generated using one-dimensional analysis only.

The present research utilizes a computer program for one-dimensional spectral analysis (14), as a subroutine in the model. For any data of an elevation trace, the program computes the coefficients, a and b, of every harmonic component. This provides enough information to compute the amplitude, phase, and the contribution of any component to the total variance of the original function.

The data used for spectral analysis consists of elevation measurements from plots of the dimensions shown in Figure 2.3. The data was a part of a study conducted by Van Doren [38] at Wooster, Ohio. Analysis was done for the plots which were plowed and then disked four times. Other plots were disked fewer times, and would probably exhibit less isotropy due to deeper tillage marks.

The results of spectral analysis are presented in the form of a curve showing the relationship between different harmonic components and the corresponding contributions to the total variance, or power. This curve is called the power spectrum.

A power spectrum of the plot used in this study is shown in Figure 2.4 The spectrum is divided into two types of roughness: the macro-roughness, which is the part composed of waves with lengths greater than 30 cm; and the micro-roughness, which is the part composed of waves with lengths less than or equal to 30 cm. The rill pattern, being formed of small-scale surface irregularities, is considered to be represented by the micro-roughness. Therefore, the wave with the highest peak, in the micro-roughness range of the spectral density function, is assumed to be the "basic" wave.

Figure 2.4 indicates that some of the waves in the macro-roughness range may have the greatest contribution to the variance of the surface. Those large waves are attributed to local topographic variations combined with the effect of tilling. Such waves have little effect on the formulation of the elementary rill pattern on the surface, and are ignored.

2.3 Generation of Surface with Regular Rill Pattern

In light of the assumptions and the observations discussed previously, it is now possible to lay out the procedure followed in this model for

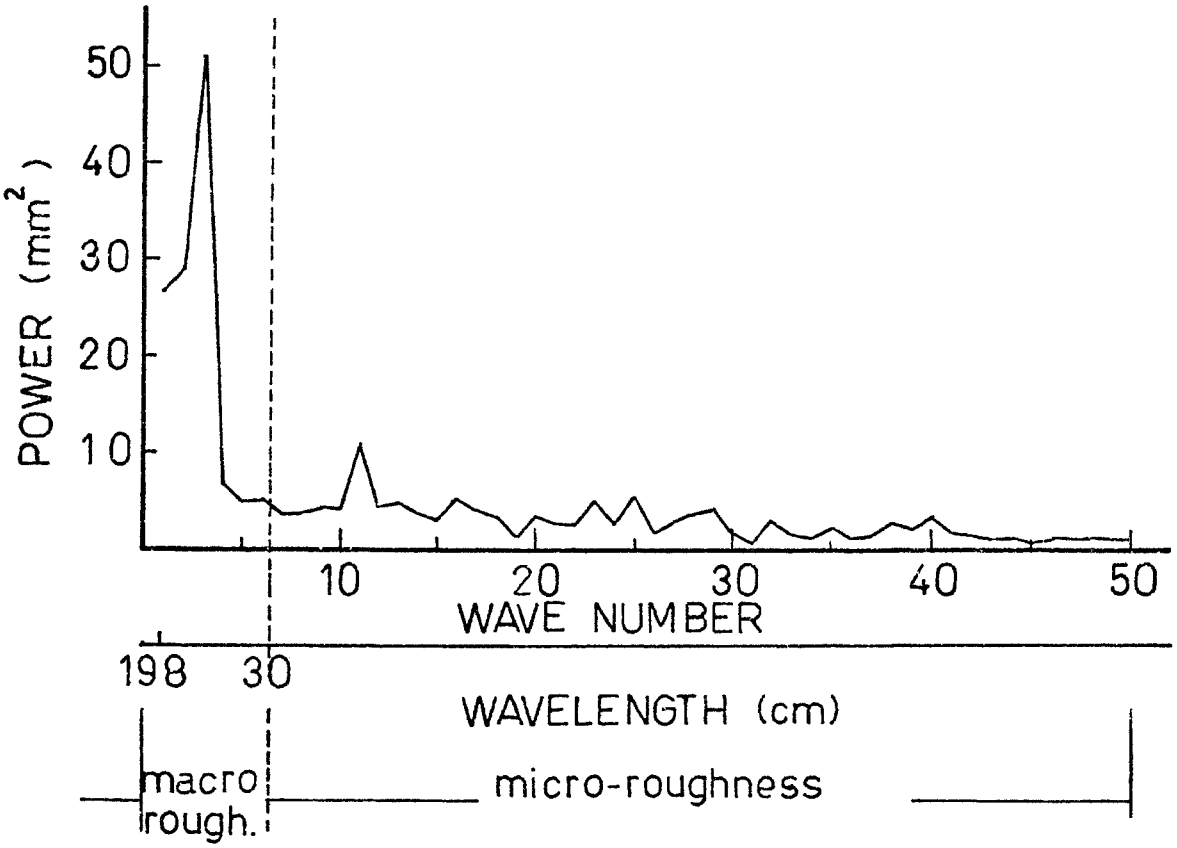

Figure 2.4 Spectral Density Function of Surface Roughness

generating a random surface on the basis of spectral analysis. The procedure is composed of two major steps. The first step is the spectral analysis of the roughness data. The second step is the numerical generation of the surface, based on the characteristics obtained from the first step.

(a) Analysis of the Data

1. Perform spectral analysis on each one of the elevation traces obtained from the measurement plot.

2. Compute the average harmonic components by averaging the coefficients a and b from all elevation traces. The resulting composition of harmonic components is regarded as the spectrum of the measurement plot.

3. From within the range of micro-roughness, pick up the wave component with the highest contribution to variance. This is the basic wave.

4. Deduct the basic wave from each of the original elevation traces to obtain the residual data. The residual data is treated as a random component and is represented by a normal distribution.

5. Compute the mean and the standard deviation of the residual data from each trace. Then compute the average values which are the mean and the standard deviation for the whole plot.

The output of this step is the length and amplitude of the basic wave, the mean, and the standard deviation of the residual data.

(b) Generation of the Surface

The random surface is generated by superposing a matrix of humps, which represent the basic wave, on a plane surface, which has a slope equal to the average slope of the actual surface. As shown in Figure 2.5, a hexagonal mesh is used to define the low zones around the humps. To obtain the elevations of the nodal points, and the hump centers, a random component drawn from the distribution of the residual data is added to the elevation of the basic wave.

The selection of a hexagonal mesh to simulate the elementary rill pattern is based on several considerations. In a rectangular grid, there is a possibility of three streams merging at a single point, since we have four branches connected together at each nodal point. This situation is seldom met in nature (34). With three members only meeting at each nodal point, the possibility of three streams merging at one point is much less. Accordingly, a hexagonal mesh provides a more realistic representation of a stream network. A hexagonal mesh is also a closer simulation of the actually curved rills. Moreover, a square mesh provides isotropy in two directions only, as shown in Figure 2.6, whereas a hexagonal mesh provides three directions of isotropy, as shown in Figure 2.7.

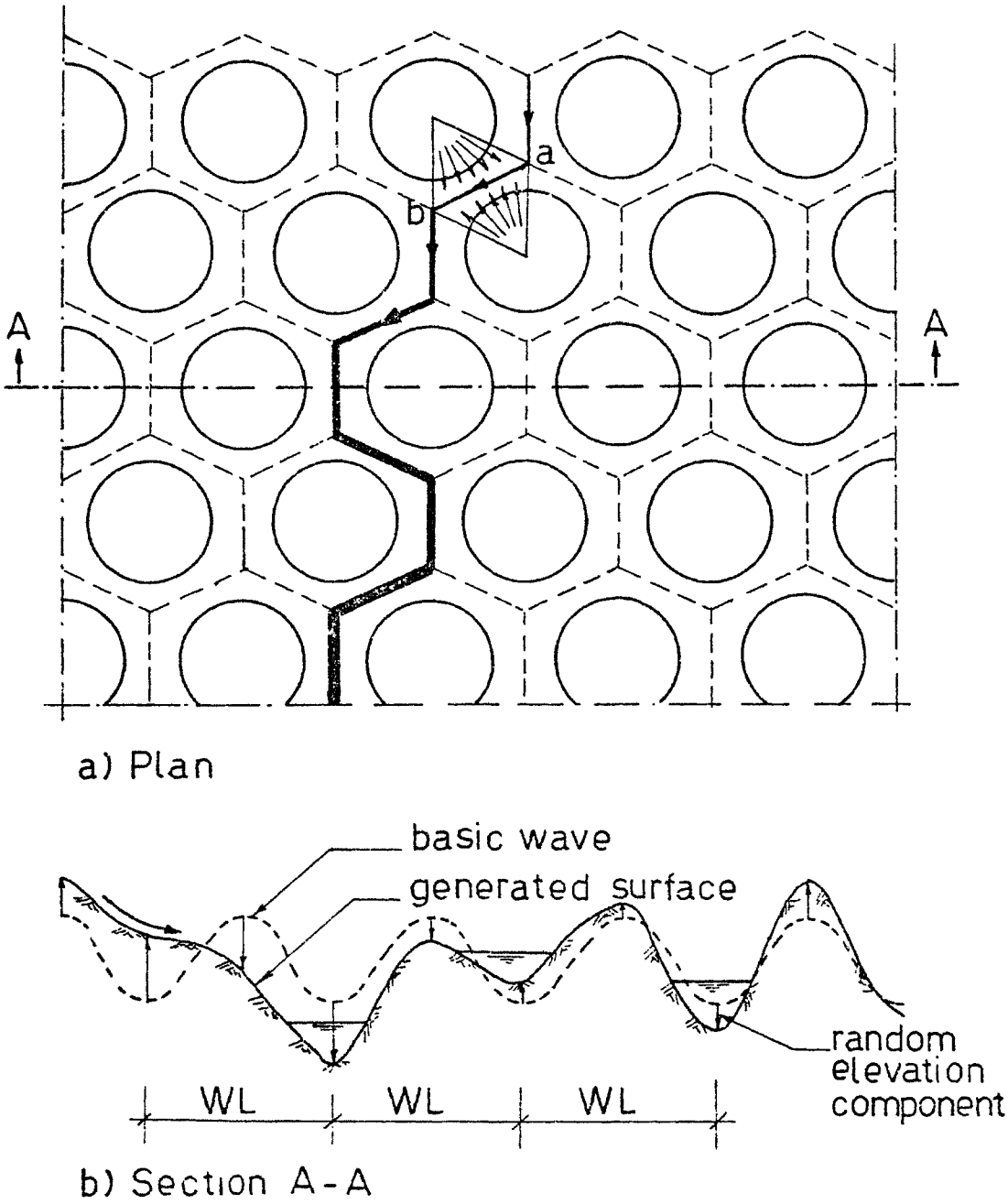

Figure 2.5 Simulation of Surface Roughness

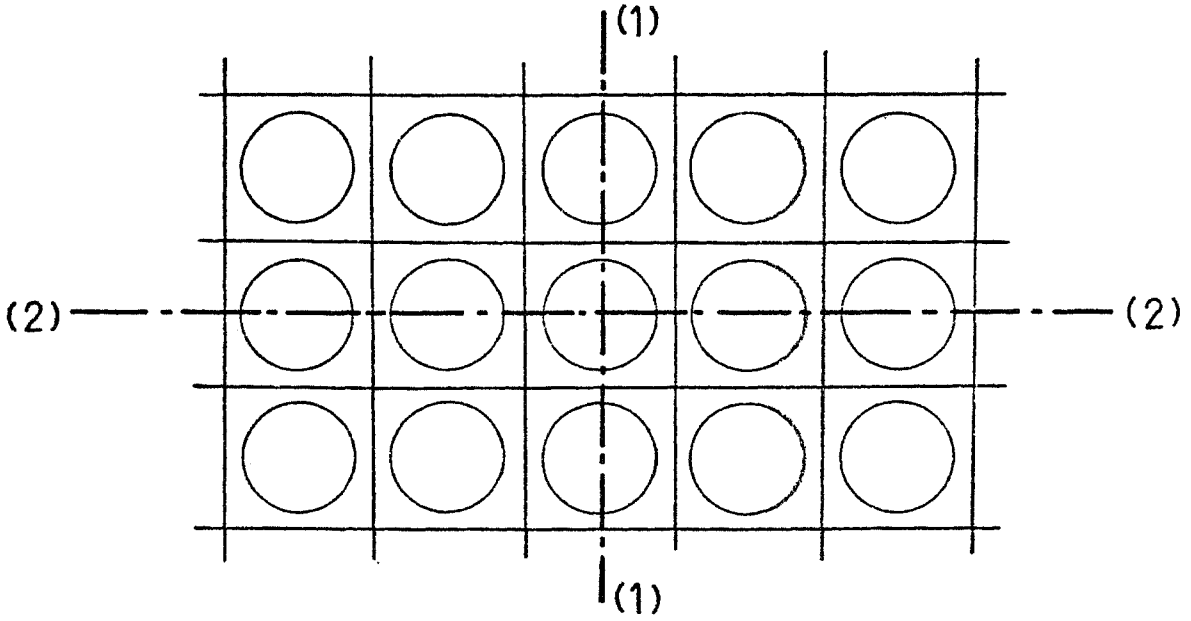

Figure 2.6 Isotropy in Square Rill Pattern

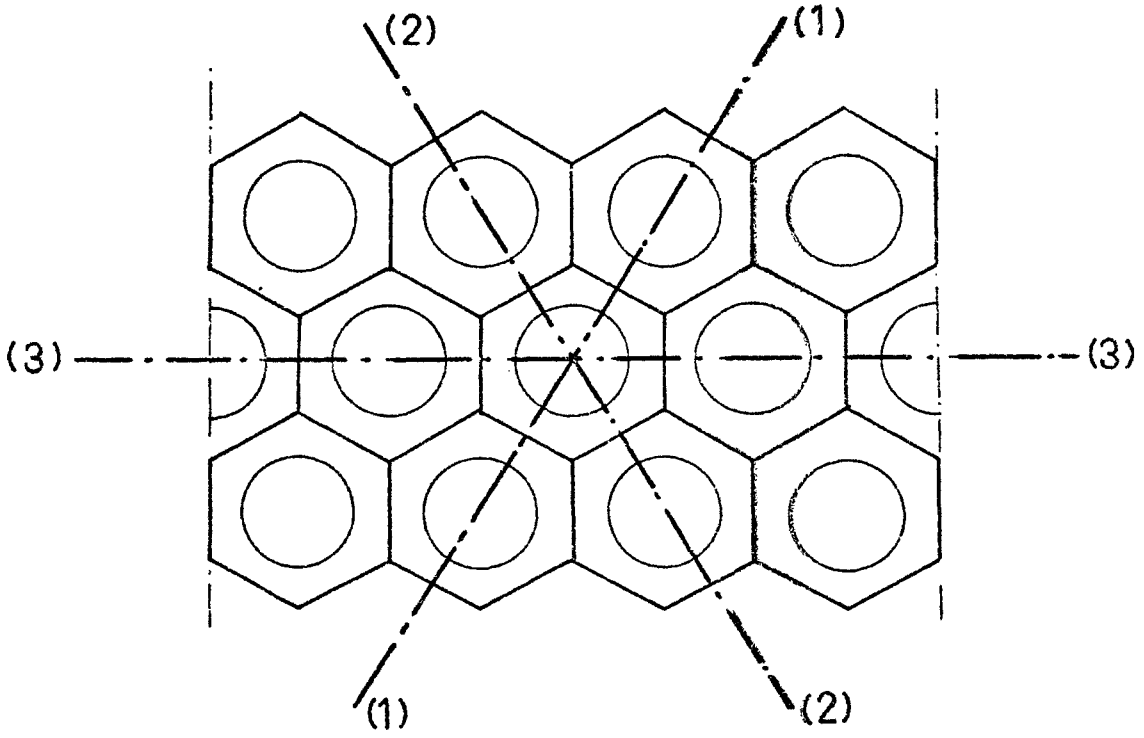

Figure 2.7 Isotropy in Hexagonal Rill Pattern

2.4 The Method of Zero-Crossing Analysis

A zero crossing is defined as the intersection of the continuous function, $x(t)$, with its mean line (Figure 2.8). Each point at which the function $x(t)$ ceases to decline and starts to rise, or ceases to rise and starts to decline, is called a turning point. A turning point is a peak when it is a relative maximum and a trough when it is a relative minimum. The longitudinal distance along the mean line between successive zero crossings is the zero crossing distance. If there are more than one turning point in a zero crossing distance, the peak (or trough) with the largest departure from the mean line will be considered the only peak (or trough) in this distance.

The vertical distance between a peak and the mean line is the positive amplitude, (a_+), and between a trough and mean line is the negative amplitude, (a_-). Finally, the sum of the positive and negative amplitudes $(a_+ + a_-)$ is the wave height and also the sum of two adjacent zero crossing distances is the wave length.

Zero-crossing analysis for long records are analyzed by means of a computer program. The first step is to identify the mean line. This can be done by the following procedure. The record is divided into q equal segments, such that each segment contains about 2 to 5 waves. For each part, the mean surface level is calculated and considered as a point at the center of the segment. Now there are q points, at the center of the q segments, and each point represents the the mean surface level within that part. The problem is to pass an appropriate curve through these q points such that it can be considered as the mean line of the record. A third degree polynomial is selected for this

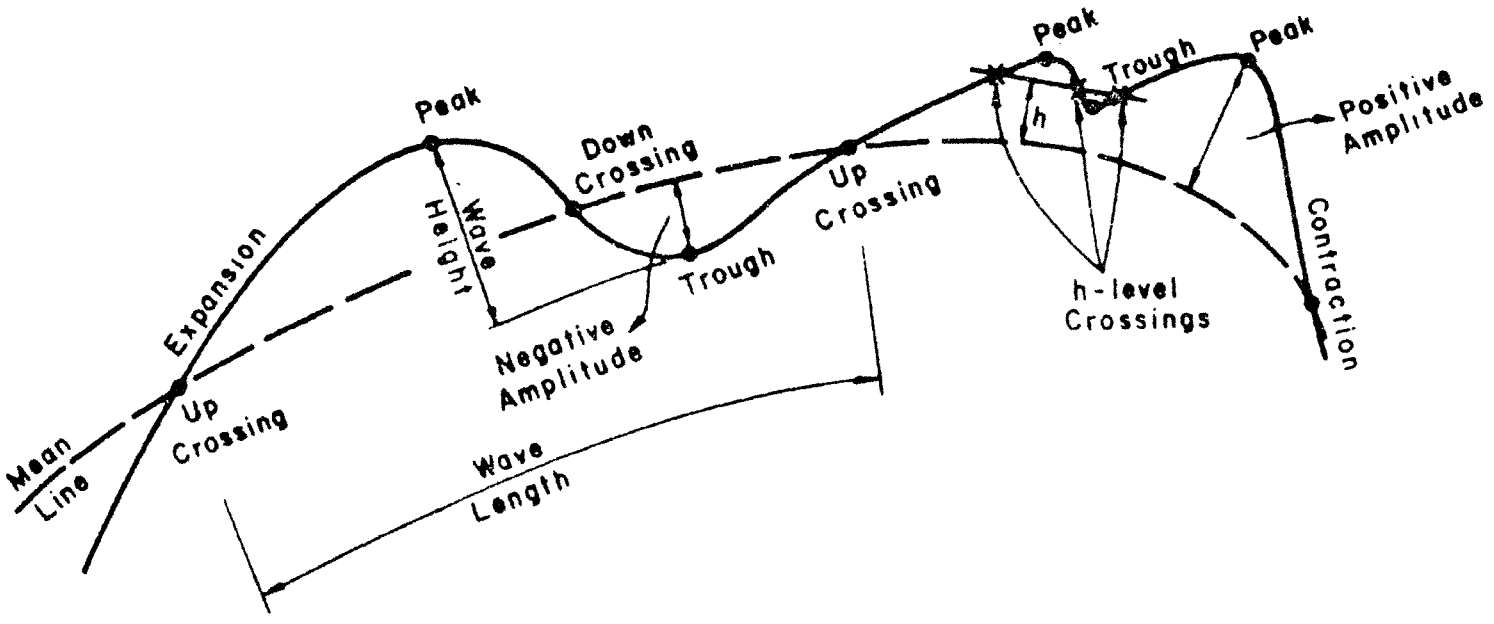

Figure 2.8 Parameters used in Zero-Crossing Analysis
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purpose, so that not only the profile is unique and continuous, but also its first and second derivatives representing slope and curvature.

When the profile of the mean line is defined, the problem of determination of the crossings with the mean line can be reduced to the determination of the crossings of the mean-removed data with the horizontal axis. The sequence of wavelengths in any elevation trace, as shown in Figure 2.9, is represented by WL_1, WL_2, ... The computer program for zero-crossing analysis [19] provides the mean, the standard deviation, and the statistical distribution of the random variables representing wavelength, WL; positive amplitude, A; and negative amplitude, B.

The zero-crossing analysis was performed on the same roughness data from Wooster, Ohio. First, each one of the elevation traces was analyzed separately. Then, all of the traces were considered and analyzed as one record. The results are shown in Table 2.1. The average values for the wavelength and the waveheight are 17 cm and 29.5 mm, respectively.

The method of zero-crossing analysis can be more useful in studying the variation of the hump size. The results can be used to generate a random surface with a random rill pattern.

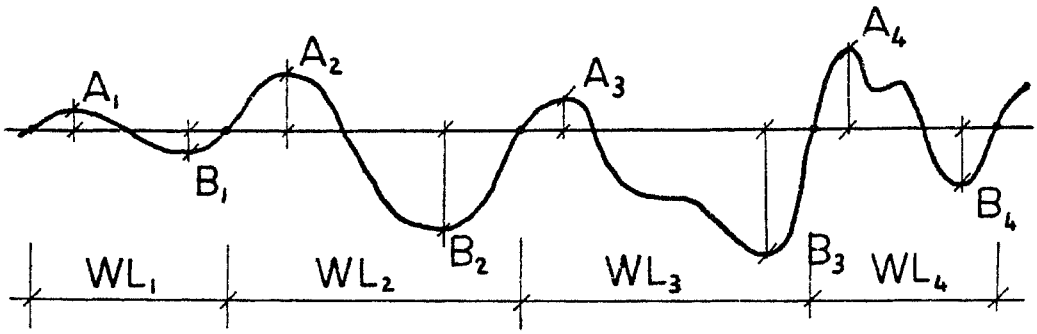


Figure 2.9 Sequences Computed in Zero-Crossing Analysis

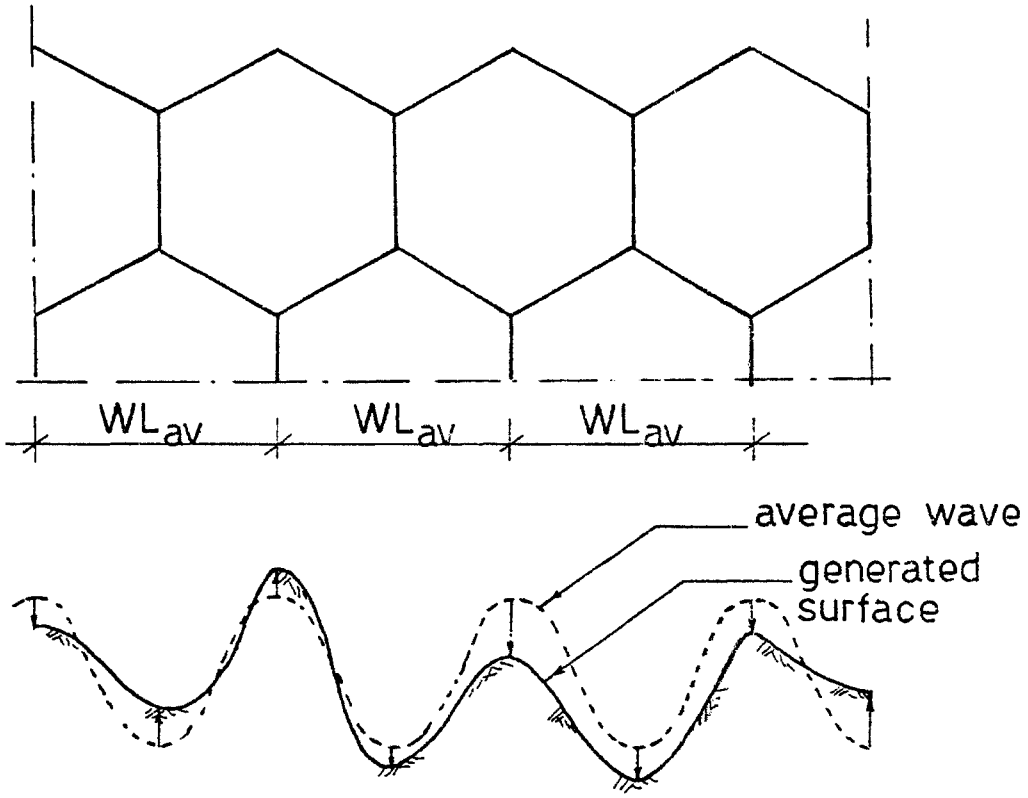


Figure 2.10 Average Wave used in Constructing a Hexagonal Rill Pattern

TABLE 2.1 RESULTS OF ZERO-CROSSING ANALYSIS

	MEAN VALUE			
Elevation trace Number	W L (cm)	+ Amp. (mm)	- Amp. (mm)	waveheight (mm)
1	11.04	9.60	12.99	22.59
2	13.54	14.50	15.14	29.64
3	12.89	12.16	17.96	30.12
4	12.23	12.34	12.86	25.20
5	11.28	13.19	14.92	28.11
6	27.72	14.68	22.45	37.13
7	19.53	14.19	18.56	32.75
Combined	13.96	13.52	15.23	28.75

Consider the elevation trace shown in Figure 2.9. The sequence of wavelengths can be expressed as follows:

$$\begin{aligned} WL_1 &= WL_{av} + X_1^1 + X_2^1 \\ WL_2 &= WL_{av} + X_1^2 + X_2^2 \\ &\vdots \\ WL_n &= WL_{av} + X_1^n + X_2^n \end{aligned} \tag{3.2}$$

where X_1^i and X_2^i are two random components applied at the two ends of the distance, WL_{av}, in Figure 2.10.

It is reasonable to assume that X_1^i and X_2^i are two realizations of the same random variable, X. This variable is assumed to have a uniform distribution. The problem is then reduced to finding the parameters of this distribution. This can be simply done by computing, for each element, WL_i, of the wavelength sequence. The corresponding value of X_i is

$$X_i = \frac{1}{2}(WL_i - WL_{av}) \tag{3.3}$$

Then the mean and the standard deviation of X can be computed.

On the basis of the assumptions of homogeneity and isotropy, we can use the same random variable, X, in the two directions, across and along the slope surface.

2.5 Generation of Surface with Random Rill Pattern

The procedure to generate the surface with random rill pattern consists of the following steps:

1. Using WL_{av} as the width of the hexagon, generate a regular hexagonal mesh.

2. From the uniform distribution between the interval, (0,1), draw a random number for each nodal point. This number is used to determine the direction in which the random component of X will be applied. This is done according to the rule given in Table 2.2 below.

TABLE 2.2 DIRECTIONS OF RANDOM COMPONENT

Value of Random Number Drawn from U(0,1)	Direction of Random Component
$0.0 \leq r < 0.25$	upward
$0.25 \leq r < 0.50$	downward
$0.50 \leq r < 0.75$	left
$0.75 \leq r < 1.00$	right

3. From the uniform distribution of X, draw a random number for each nodal point. This number specifies the magnitude of the shift in the direction determined in Step (2).

4. Use the distribution of the residual data (Sec. 2.3) to generate a random component for the elevation of every nodal point.

Figures 2.11 and 2.12 show the rill patterns generated using hexagonal and random mesh, respectively.

2.6 Concluding Remarks

The use of the zero-crossing analysis to generate a random rill pattern may represent a better approximation of the surface. However, this irregularity imposes great difficulties in the coding of the flow-routing and erosion mechanisms. Therefore, the present erosion model uses the hexagonal mesh as a rill pattern. A limited number of calculations were made with a random rill pattern to assess the influence of rill pattern.

While the zero crossing analysis offers advantages, the present model uses the spectral analysis for analysis of the roughness data. The main reason for this is that spectral analysis allows us to recognize the relative importance of large-scale and small-scale surface irregularities. Therefore, we can define the part of the data which contributes most to the formation of the rill pattern. Moreover, the method of spectral analysis, although not fully utilized in this model, provides greater potential for improvement of surface roughness modeling.

The mechanism of selecting only one wave component of the spectrum as the basic wave created a problem in the simulation process. This

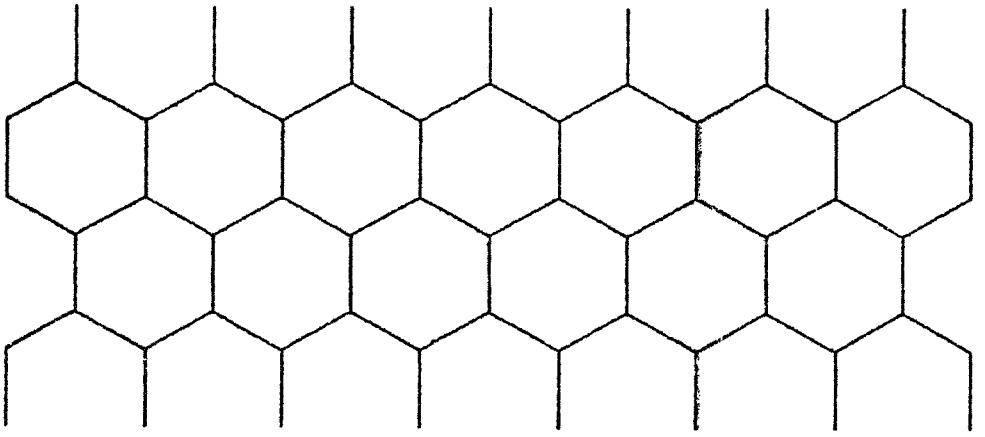


Figure 2.11 Uniform Rill Pattern

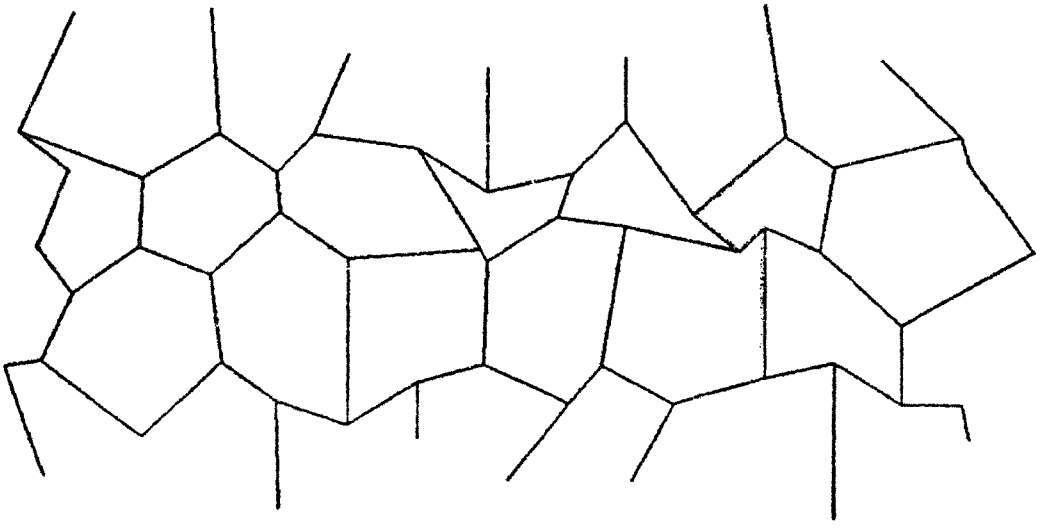


Figure 2.12 Random Rill Pattern

is because the amplitude of this wave alone is not large enough to represent the humps. We note that the average wavelength and wave height obtained by using the zero-crossing analysis are about 17 cm and 29.5 mm, respectively (see Table 2.1). This is, the average amplitude can be taken as about 15 mm. On the other hand, the length and amplitude of the basic wave as determined by spectral analysis of the same data are 18 cm and 3.7 mm, respectively. Thus the amplitude of the basic wave underestimates the height of the humps.

In the present program, the hump height is generated by a simplified solution. For a basic wave of length WL, the length of the hexagon's side is equal to $WL/\sqrt{3}$. If the surface is inclined with an angle of θ, then each hump center is raised by the amount $\frac{\omega L}{\sqrt{3}} \sin \theta$. For a slope of 20°, which is the slope used in this analysis, the additional increment, $\frac{WL}{\sqrt{3}} \sin \theta$, is equal to 35 mm, about twice the average amplitude computed using zero-crossing analysis. This value is equal to 18.1 mm for a ten-degree-slope. When compared with the results of zero crossing analysis, we can see that the simplified approach represents a reasonable approximation. This procedure makes the elevation of the hump center, before we superpose the basic wave or the random component, is equal to the elevation of the highest nodal point around it. Then the basic wave and the random increments in elevation are added. Due to this randomness, some of the humps may be lower than some of the surrounding nodal points. Our model allows for some rill segments to be eliminated, depending upon the original roughness data.

3. EROSION MODEL

The subject of this chapter is the model for computation of erosion in rills and over interrill areas. Emphasis is placed on the development of computational procedures which are suitable for the surface model and are based on principles of hydraulics and sediment transport mechanics.

The present analysis considers only erosion of soil particles by the shearing action of flow in rills and over interrill areas. In other words, the direct detachment and transport process due to rainfall impact is not accounted for. The rainfall impact detaches soil particles from clods and causes the particles or aggregates of particles to be transported in a fashion similar to that of cohensionless soil particles (7).

Preliminary experiments were performed to measure the detachment of soil particles under the impact of raindrops. The results, presented in Appendix A, suggest that for a given soil and impact energy, a certain number of drops are required to break up a cohesive soil clod. After this the material would be transported as a cohesionless soil. Thus the erosion model presented here is general and can be adapted for cohesive soils by addition of a threshold rainfall, which is the amount required to break up the clods.

Consider the random surface composed of a matrix of humps surrounded by rills connecting the lower points. For the purpose of erosion computation, the geometrical configurations of the surface are simplified. The humps are assumed to be in the form of hexagonal

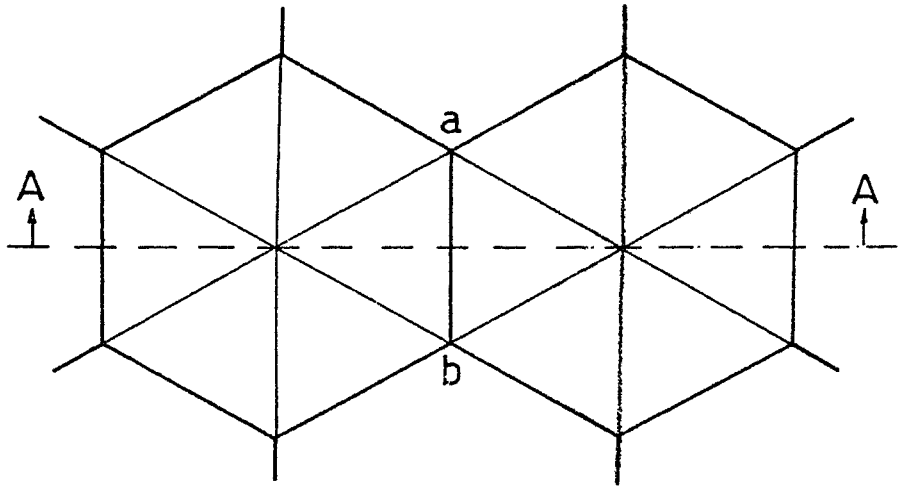
pyramids; the slope of each of the six sides is dependent upon the random outcome of surface generation. Rills are assumed to be formed of channels with triangular cross sections with the side slopes of the adjacent humps forming its boundaries, as shown in Figure 3.1. A channel between two nodal points is termed a "rill segment". In the remaining sections of this chapter, the equations of erosion of rills and of humps are derived.

3.1 Rill Erosion Equation

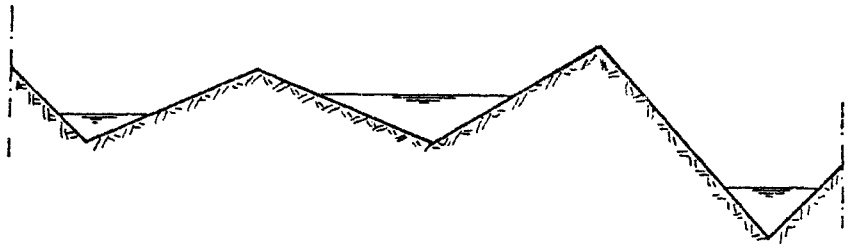
Consider a rill segment, ab, as shown in Figure 3.1(a). Let q_1 be the rate of water flow received from upslope at point a, and q_2 be the flow at b. q_2 is greater than q_1 by the amount of water drained from the two adjacent side slopes. The flow in the rill segment, ab is actually a spatially-varied flow with the rainfall acting as a lateral inflow. Researchers such as Yoon and Wenzel (41), Li et al (18), and Komura (15) have considered the overland flow as spatially-varied flow. However, since the present model deals with the erosion in short rill segments, equations of uniform flow are used.

Erosion due to rill flow is based on the concept of tractive force (10). Consider the triangular cross-section of a rill segment, as shown in Figure 3.2. The average value of the tractive force per unit wetted area, i.e., the unit tractive force, τ_0, is given by:

$$\tau_0 = \gamma R S_f \qquad (3.1)$$

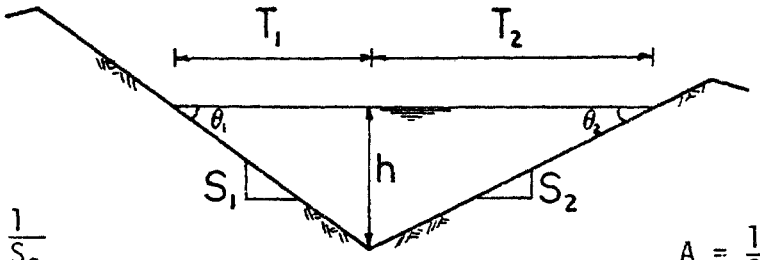


a) Plan



b) Section A-A

Figure 3.1 Surface Idealization



$$C_1 = \frac{1}{S_1} + \frac{1}{S_2}$$

$$C_2 = \frac{1}{Si\theta_1} + \frac{1}{Si\theta_2}$$

$$C_3 = C_1/C_2$$

$$A = \frac{1}{2}h^2\left(\frac{1}{S_1} + \frac{1}{S_2}\right) = \frac{1}{2}h^2 C_1$$

$$p = h\left(\frac{1}{Si\theta_1} + \frac{1}{Si\theta_2}\right) = h\,C_2$$

$$R = \frac{1}{2}h\,C_3$$

Figure 3.2 Rill Cross-section

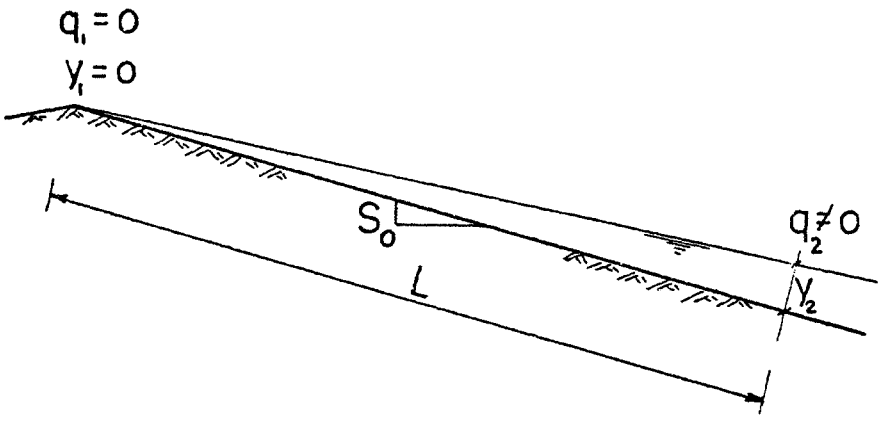


Figure 3.3 Flow Over Interrill Area

where

γ = unit weight of water;

R = hydraulic radius of the channel = Area/wetted perimeter; and,

S_f = slope of the energy grade line.

Henderson (13) indicates that the slope of the energy line, S_f, can be approximated by the bed slope, S_0, for a mountain type channel. Using this approximation, Equation (3.1) becomes:

$$\tau_0 = \gamma R S_0 \tag{3.2}$$

According to Chow (4), the unit tractive force in channels, except for wide open channels, is not uniformly distributed along the wetted perimeter. Therefore, it is more appropriate to use the tractive force per unit length of the rill as expressed by the following equation:

$$F_0 = \tau_0 \times P = \gamma A S \tag{3.3}$$

where

P = wetted perimeter; and

A = cross-sectional area of the flow.

In terms of the geometrical features of the triangular cross-section, as given in Figure 3.2, we have:

$$F_0 = \frac{\gamma S_0}{2} h^2 \left(\frac{1}{S_1} + \frac{1}{S_2}\right) \tag{3.4}$$

Neglecting the variation of S_0 along the segment ab, the value of F_0 is then dependent upon h at any point. The values of h_1 at a and h_2 at b depend on the corresponding values, q_1 and q_2. To obtain the flow depth, h, we start with the well-known Manning equation,

$$V = \frac{1}{n} R^{2/3} S_f^{1/2} \tag{3.5}$$

where

V = the mean velocity in meter/sec;

R = the hydraulic radius in meters;

S_f = the slope of the energy line; and,

n = the coefficient of roughness, specifically known as Manning's n.

Using the approximation $S_f = S_0$, and the relation $q = V \cdot A$, we get:

$$q = \frac{A}{n} R^{2/3} S_0^{1/2} \tag{3.6}$$

which can be expressed in terms of h as:

$$q = \left(\frac{1}{2} \frac{c_1 h^2}{n}\right)\left(\frac{1}{2} c_3 h\right)^{2/3} S_0^{1/2} \tag{3.7}$$

Therefore,

$$h = \frac{2^{5/3} n q}{c_1 c_3^{2/3} S_0^{1/2}} \tag{3.8}$$

where c_1 and c_3 are as defined in Figure 3.2.

The flow in rills has been so far treated as open channel flow. The flow characteristics are then used to compute the amount of soil eroded. This scheme implies that the effect of sediment already carried in the flow is not considered. That is, the concentration of sediment is assumed small enough so that the equation of motion for sediment-laden water can be approximated by the eqaution of motion for water only.

According to Li et al. (18), the continuity equation for sediment can be expressed as:

$$\frac{d\, q_s}{dx} = p_s \tag{3.9}$$

where

q_s = the sediment discharge per unit width of channel, and

p_s = the fine-sediment pick-up rate per unit area.

q_s is a function of the flow characteristics and specifically, the flow tractive or shearing force. The bed load equation derived by Kalinske (10) is used to obtain q_s. It is expressed in the nondimensional form as:

$$\frac{q_s}{U_* D} = a_s \left[\frac{U_*^2}{(\frac{\rho_s}{\rho_w} - 1)\, g\, D} \right]^p \tag{3.10}$$

where

q_s = the sediment discharge including suspended sediment in volume of material per unit time and unit width;

U_* = the friction velocity;

D = the mean sediment size;

ρ_s and ρ_w = densities of sediment and water, respectively;

g = the gravity acceleration;

a_s = a constant; and

p = a dimensionless exponent.

The reasons for the use of Kalinske's equation are primarily empirical. Komura (15) used it in a mathematical model for slope erosion by overland flow and established the range of values for some parameters in the equation, when applied to overland flow. Calculations with Eq. (3.18) (Appendix B), gave results that are in reasonable agreement with measured rill erosion by Meyer (22). From theoretical considerations (40) there is no compelling reason to choose any of the existing sediment transport equations over any other.

Substituting for U_* by τ_0/ρ_w, q_s can be expressed as:

$$q_s = \frac{\beta_1}{\rho_w^{(1+2p)/2}} \tau_0^{(1+2p)/2} \qquad (3.11)$$

in which τ_0 = the unit tractive force and

$$\beta_1 = \frac{a_s}{\left(\frac{\rho_s}{\rho_w} - 1\right) g^p D^{p-1}} \qquad (3.12)$$

Assuming that a similar relation exists between the "total" sediment discharge per unit length of the channel, Q_s, and the corresponding tractive force per unit length, F_0, Equation (3.11) can be rewritten in the form:

$$Q_s = \frac{\beta_1}{\rho_w^{(1+2p)/2}} F_0^{(1+2p)/2} \tag{3.13}$$

Similarly, the continuity equation for sediment, given by Equation (3.9), can be modified as:

$$\frac{dQ_s}{dx} = P_s \tag{3.14}$$

in which P_s is the fine-sediment pickup rate per unit length of the channel.

For a long slope, the average erosion rate per unit area is defined by Li et al. (18) as the average pickup rate along the slope and is expressed as:

$$E = \frac{1}{L} \int_L P_s \, dx \tag{3.15}$$

where L is the length of the slope in the x-direction. But for the short segments considered in our case, E is taken as directly equal to P_s. Accordingly, the erosion rate in volume per unit length of the channel, E_v, is given by:

$$E_v = \frac{dQ_s}{d_x} \tag{3.16}$$

Taking the derivative of Equation (3.13), we obtain:

$$E_v = \left(\frac{1}{2} \frac{(1+2p)\ \beta_1}{\rho_w^{(1+2p)/2}} \frac{d\ F_0}{dx}\right) F_0^{(2p-1)/2} \tag{3.17}$$

in which F_0 at any point is obtained from Equations (3.4) and (3.8), in terms of the water discharge.

Considering, again, the size of the channel, the term $\frac{dF_0}{dx}$ can be rewritten in difference form. That is, for the rill segment of length ΔL, the erosion rate of rills, in volume per unit time, E_v, can be expressed as:

$$E_r = \frac{1}{2} \frac{(1+2p)\,\beta_1}{\rho_w^{(1+2p)/2}} \left(\frac{F_{0_2} - F_{0_1}}{\Delta L} \right) \left(\frac{F_{0_1} + F_{0_2}}{2} \right)^{\frac{2p-1}{2}} \times \Delta L$$

and the final computational form for E_r becomes:

$$E_r = \frac{1}{2} \frac{(1+2p)\,\beta_1}{\rho_w^{(1+2p)/2}} (F_{0_2} - F_{0_1}) \left(\frac{F_{0_1} + F_{0_2}}{2} \right)^{\frac{2p-1}{2}} \qquad (3.18)$$

where β_1 is given by Equation (3.12) and F_{0_1} or F_{0_2} are computed from Equations (3.4) and (3.8).

3.2 Interrill Erosion Equation

A similar approach is used to express the erosion rate of interrill areas. The flow in this case is approximated by a sheet flow with $q_1 = 0$ at the top and q_2 at the bottom. Consider a surface with slope S_0 and length L, as shown in Figure 3.3. Assume that the flow depth increases linearly downslope from $y_1 = 0$ at the top to y_2 at length L. The unit tractive force resulting from this flow at points a and b, respectively, is given by:

$$\tau_{0_1} = \gamma\, y_1\, S_0 = 0 \tag{3.19}$$

and

$$\tau_{0_2} = \gamma\, y_2\, S_0 \tag{3.20}$$

in which the wide-channel approximation, $R \simeq y$, has been applied.

The flow depth is also determined using Manning's equation which gives, for this case:

$$q = \frac{1}{n}\, y^{2/3}\, S_0^{1/2} \tag{3.21}$$

The flow depth at any point is given in terms of the flow rate as,

$$y = \left(\frac{n\, q}{\sqrt{S_0}}\right)^{3/5} \tag{3.22}$$

Based on the continuity equation for sediment (Equation 3.9), in conjunction with Kalinske's bed load formula, an expression for erosion rate of interrill areas can be written as:

$$E_i = \frac{1}{2}\, \frac{\beta_1\, (1+2p)}{\rho_w^{\frac{1+2p}{2}}}\, \frac{1}{L} \times \tau_{0_2}^{\frac{2P+1}{2}} \tag{3.23}$$

where

E_i = erosion rate of interrill areas in volume per unit area per unit time;

β_1 = as given in Equation (3.12); and,

τ_{0_2} = the unit tractive force, or shear stresses, at distance L downslope, and is computed from Equations (3.22) and (3.20).

Although the water flows over the humps in a more or less radial fashion, the present analysis assumes a one-dimensional flow in the direction of the centerline of each one of the six sides of the hexagonal pyramid. Furthermore, the total amount of erosion from each triangular side is computed for the equivalent rectangle, as shown in Figure 3.4.

3.3 Concluding Remarks

It is important to notice that the derived erosion equations do not compare the transport capacity of the flow with its detachment capacity. The model, for simplicity, assumes that the slope surface will always provide the overland flow with an adequate sediment load. For cohesive soils this requires that rainfall impact detach sufficient soil particles to provide the sediment load. Where this requirement is not satisfied the model can be modified as described in Appendix A.

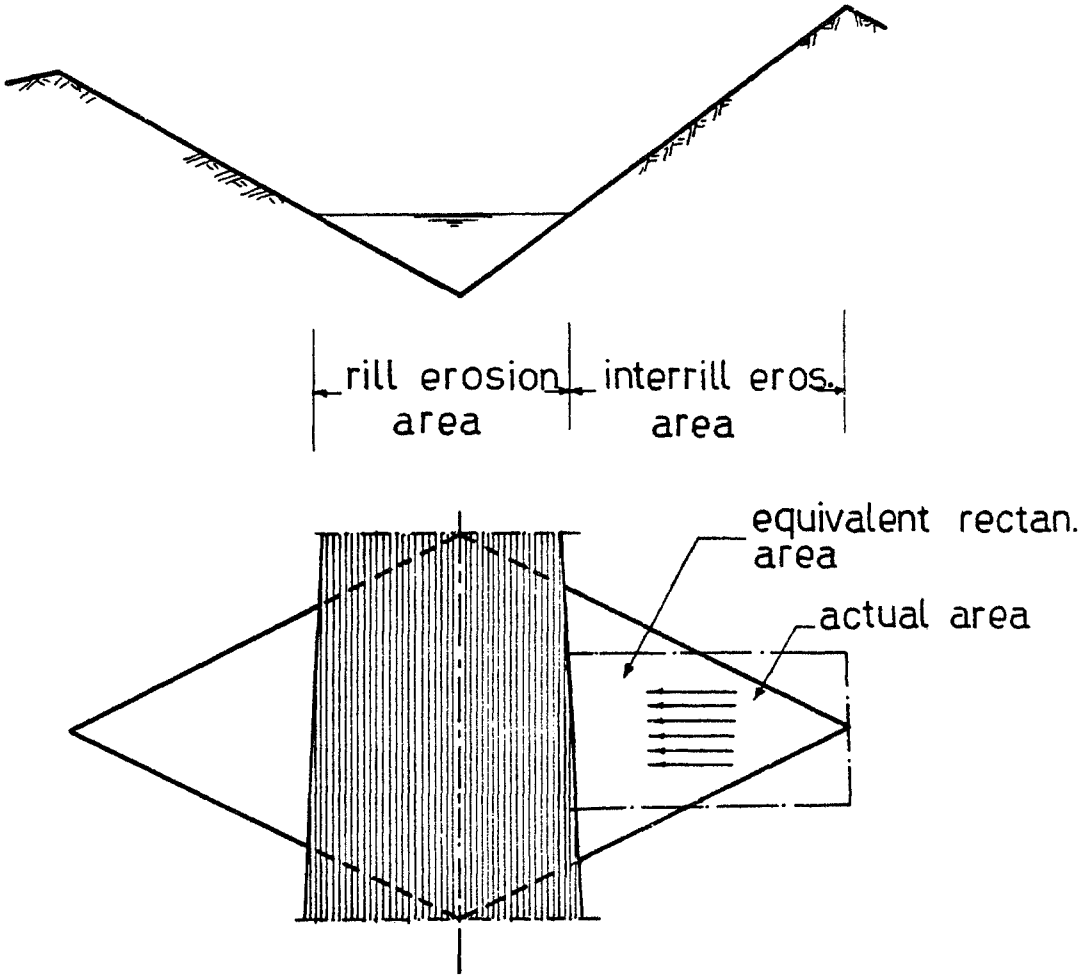


Figure 3.4 Geometrical Basis for Interrill Erosion Computation

4. SIMULATION MODEL

Based upon the theoretical and practical considerations discussed in Chapters 2 and 3, a computation scheme is constructed to simulate the process of slope erosion by rainfall. A random surface is first generated on the basis of the statistical properties of the original surface, as explained in Chapter 2. The overland flow is assumed to move downslope following the rill pattern created by a hexagonal mesh.

The computation schemes for simulating the main features of the model are described in Section 4.1. Those are the routing of the overland flow and the sediment load over the surface, the topographical changes due to erosion, and the changes in the process with successive time intervals. In addition, there are several auxilliary mechanisms which are very important; these are discussed in Sec. 4.2.

4.1 Main Features of Simulation Model

4.1.1 Routing of Water and Sediment

Part of the rain falling on the test area is assumed to infiltrate through the surface layer. The rate of infiltration is known to decay with time. However, for simplicity, the model assumes a constant runoff coefficient, RNF, which is the fraction of rainfall that becomes runoff. This part is divided between the rills and the interrils, or the humps. However, the water falling on the

interrill areas, in excess of infiltration, is drained to the surrounding rill segments, as shown in Figure 4.1.

The flow in rills and its sediment load at any nodal point of the hexagonal mesh depends on its position in the mesh, as well as the random elevation. The hexagonal mesh allows for two types of nodal points, as represented by points a and b in Figure 4.1. Point a receives flow from two branches and discharges it in only one direction downslope. Whereas point b has only one inflow branch, then the flow routed downslope is divided between two branches.

The flow in rills moves forward only if the bed slope of the rill segment is positive. If the bed slope is either zero or negative, the flow routing of this rill is terminated at this point.

At points such as a in Figure 4.1, the flow merging from the two inflow branches is automatically directed to the third, the outflow branch. But for points such as b, the incoming water is divided between the outflow branches according to the ratio of the square root of the two bed slopes, i.e., $(SO_1/SO_2)^{1/2}$. This procedure complies with the slope exponent in Manning's formula as shown in Equation (3.5). As for the sediment load, we use the ratio of $(SO_1/SO_2)^{\frac{5}{16}(2p+1)}$ which is obtained from Equations (3.18) and (3.4) in which p is the exponent of Kalinske's bed load equation.

4.1.2 Erosion of the Surface

Erosion of a rill segment affects its geometry in both cross-sectional and longitudinal directions. The amount of soil eroded by rill flow for one time interval is computed from Equation (3.18.)

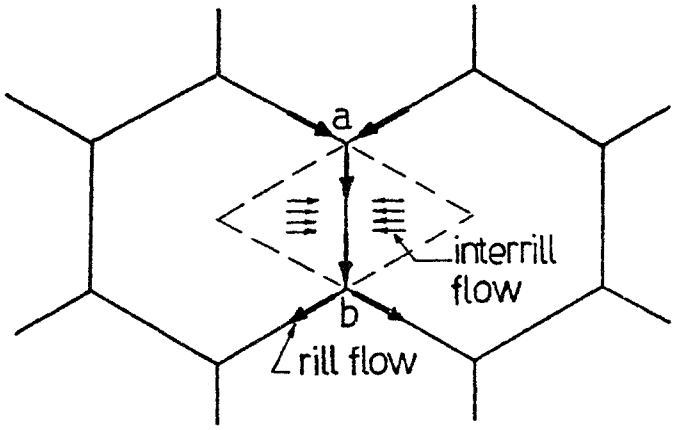


Figure 4.1 Typical Routing of Rill and Interrill Flow

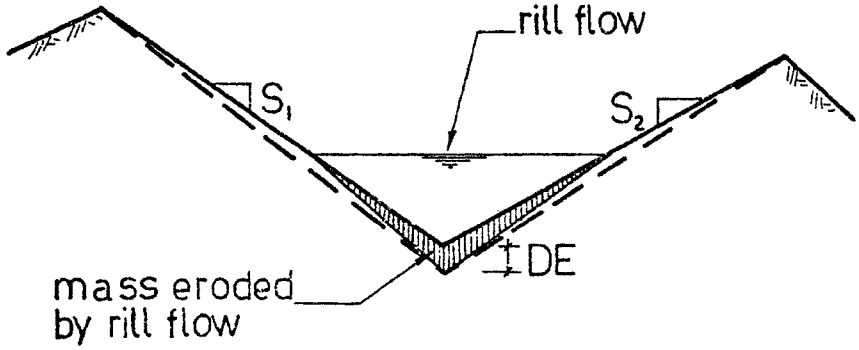


Figure 4.2 Change in Rill Geometry due to Rill Erosion

This amount is then removed from the rill cross-section as indicated by the shaded area in Figure 4.2. The bed level is then lowered by the distance, DE.

Interrill erosion is computed from Equation (3.23)for the area of the side slopes which lie above the water level. Interrill erosion is assumed to steepen the side slopes gradually. To account for this action in a simplistic manner, the new side slopes, S_1 and S_2, to be considered for the next interval, are represented by the dashed lines on Figure 4.2. This is an approximation of the actual condition which results in different side slopes below and above the water. However, this approximation eliminates a computational difficulty.

In the longitudinal direction, the rill segment is assumed to be eroded uniformly. But since more than one rill segment always meet at each nodal point, the final decrease in the elevation of this nodal point is taken to be the average of the three values of DE computed for each branch.

4.1.3 Temporal Change

The time-dependent nature of the erosion process is accounted for by computation of erosion for a number of time intervals. During each time interval, the elevations of all nodal points and humps remain constant. The changes in the surface geometry due to erosion are then computed at the end of the interval, and the new elevations of all points are used for the next time interval. The effect of the interval length on the model results is discussed later in Section 4.4.2

The water flow at any nodal point, during a time interval, is the sum of the rill flow arriving from upslope and the water drained

from the adjacent humps. The same mechanism applies for sediment load at any point. The total amount of sediment yield produced during any time interval is computed as the sum of sediment load at the nodal points at the bottom of the slope.

It has been mentioned earlier that runoff actually starts at different points on the surface after the rainfall rate has exceeded the infiltration rate. It is important to notice, however, that the computations begin at the time when the runoff that started at the top of the slope has reached the bottom. The amount of sediment eroded before that time is neglected.

4.2 Auxilliary Mechanisms

Beside the main computational schemes previously described, there is a number of auxilliary mechanisms which are very important for the simulation of the erosion process, and provide the model with more realistic features.

4.2.1 Ponding

Recalling the mechanism of flow routing discussed in Section 4.1.1, the flow in any rill segment moves forward only if the bed slope of the rill is positive. When the bed slope is either zero or negative, the model assumes that the water ponds and that the flow velocity becomes zero along this segment.

At the nodal points, where three segments are connected, the ponding mechanism is as follows. For a point such as a in Figure 4.3, ponding occurs when the branch ai has a slope less than or equal to zero. The inflow into segments ij and ik is then equal to zero. These

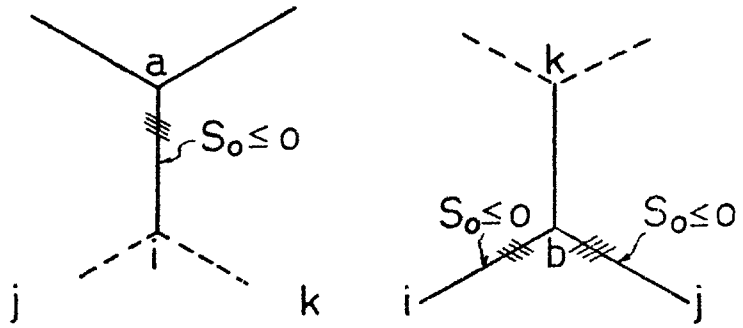


Figure 4.3 Ponding Conditions

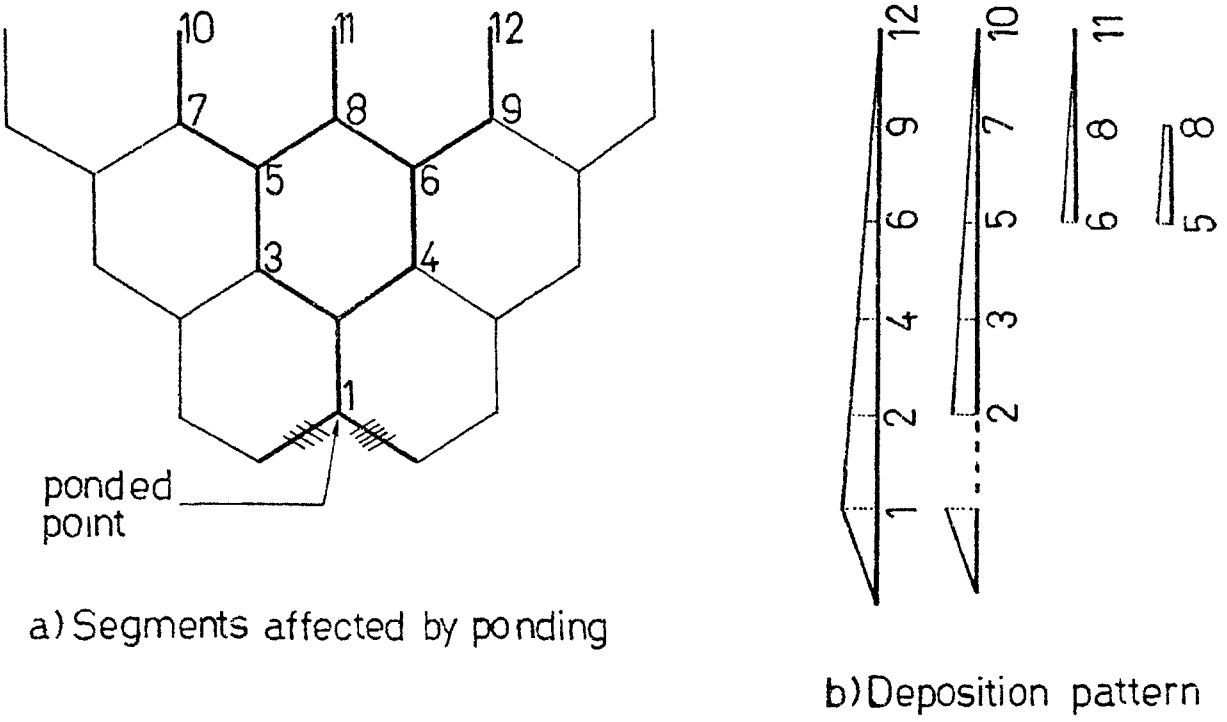


Figure 4.4 Deposition due to Ponding

rill segments then receive only water that is drained from adjacent humps. At a point such as b in Figure 4.3, complete ponding occurs only if both bi and bj have slopes less than or equal to zero. When only one of the two branches is ponded, then the flow is automatically routed through the other branch.

4.2.2 Deposition Due to Ponding

Ponding occurs when the flow reaches zero velocity. The presence of ponding also influences the velocity of flow at points some distance upstream, and causes a reduction in the erosion rate at these points. This model uses a simplified mechanism to simulate the effect of ponding on deposition, and on reducing erosion at locations upslope.

Consider the case when ponding occurs at point 1 in Figure 4.4. This means that the bedslope of the lower branches is less than or equal to zero, and there is no other possibility for routing the flow. The flow in the segment 2.1 is assumed to approach a zero velocity at point 1. The total sediment load arriving at point 1 is then deposited on the bottom of several rill segments upstream and downstream of point 1. The pattern of depositing the sediment load is also shown in Figure 4.4. The final change in the elevation of any point is the net difference between this deposition and erosion as computed from Equations (3.18) and (3.23).

4.2.3 Stability of Rills' Side Slopes

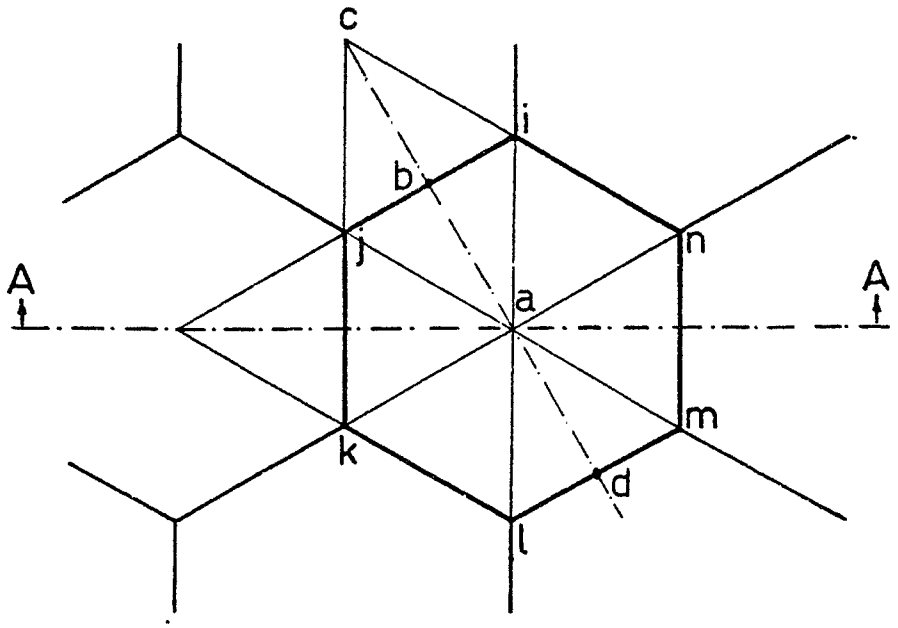
As described in Section 2.3, the process of rill development is a combination of erosion, slumping of undercut side slopes, and head

cuts. Since the progression of rill and interrill erosion steepens the side slopes, it is important to define a criterion with which we can check the stability of the side slopes at any time during the erosion process.

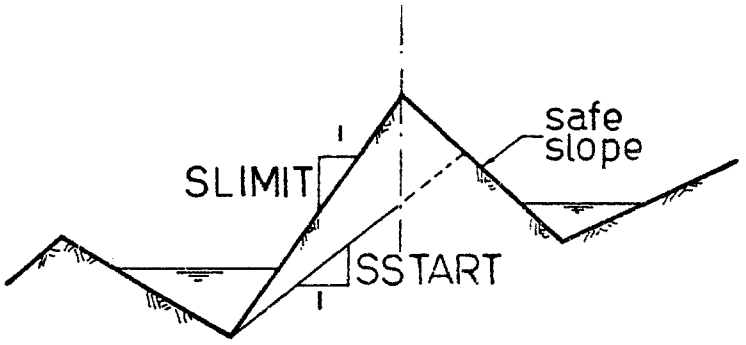
The stability criterion used in this model consists of a limiting gradient, SLIMIT, that a side slope can withstand. When the gradient exceeds SLIMIT, the slope fails and assumes a new, flatter gradient, SSTART. The side slopes are assumed to remain plane, before and after failure. The values of the two limits can be estimated from experience with the type of soil in question.

When a side slope fails, the top of the slope, which is the center of the hump, is lowered by a certain distance, as shown in Figure 4.5. Some of the sides of the hump may fail while others may be stable. Therefore, in computations, each side has its own elevation at its top. At the end of the test period, the final elevation of the hump center is computed as the average of the top elevation of the six sides.

The soil mass removed after each slope failure should be added to the sediment load of the rill segment in which failure occurred. Usually, the additional load cannot be carried by the transport capacity of the flow, and they require a more complicated account of deposition over the length of the rill. Therefore, these masses are presently ignored in the computation of the total sediment load. Due to this approximation, the model may be underestimating the total sediment yield.



a) Plan



b) Section A-A

Figure 4.5 Mechanism of Side-Slope Failure

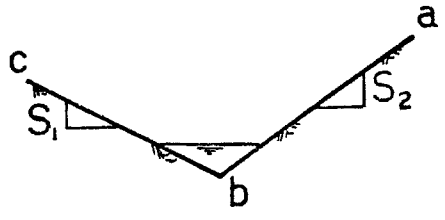


Figure 4.6 Segment with Positive Side Slopes

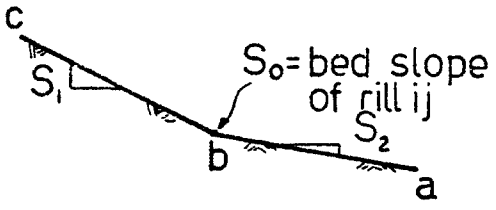
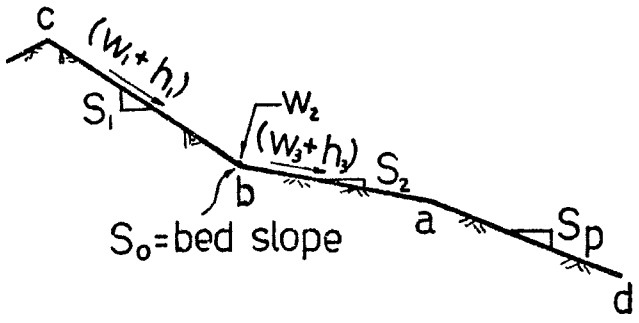


Figure 4.7 Segment with a negative side slope

4.2.4 Low Humps

In this model, the elevation of a hump is usually greater than the elevations of all six nodal points of the surrounding hexagon. however, if, due to the random designation of elevations, one or more of the six points become higher than the hump center, then this hump is called a "low" hump. For example, in Figure 4.5, if point a is higher than both points i and j, then the cross-section of the rill segment ij would have the configurations shown in Figure 4.6. In this case, the two side slopes are positive. On the other hand, if point a happens to be lower than the average elevation of ij which is represented by point b, then the rill would have the cross-section shown in Figure 4.7. Such a condition prevents the development of a rill in the first place, and the flow routing is altered.

To illustrate the various possibilities that are associated with a low hump, consider the rill segment ij with the cross-section shown in Figure 4.7. The flow will move in either the direction of in or the direction ba, depending upon the slopes S_0 and S_2 in Figure 4.7. The flow is routed in the direction of maximum slope. On the other hand, the sign of S_p (Figure 4.8) determines whether the flow passing over the negative slope, S_2, would continue over slope S_p and join the rill flow in segment ml, or would just pond at a. Figure 4.8 illustrates the possible cases and the corresponding routing considered in each case.



Sp	So	Computational mechanism
(+)	$S_o > \|S_2\|$	$(W_1+h_1)+(W_2) \Rightarrow j$
(+)	$S_o < \|S_2\|$	$(W_3+h_3) \Rightarrow ml$
		$(W_1+h_1)+(W_2)+(W_3+h_3) \Rightarrow ml$

Notations

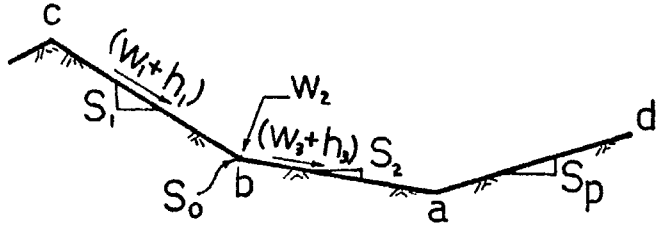
W_1: water flowing on side slope C_6

h_1: hump erosion from side slop ab

W_2: water flowing in rill ij

h_3: hump erosion from side slope bc

W_3: water flowing in side slope ba



(-)	$S_o > \|S_2\|$	$(W_1+h_1) + (W_2) \Rightarrow j$
		$(W_3+h_3) \Rightarrow a$; (ponding)
(-)	$S_o < \|S_2\|$	$(W_1+h_1) + (W_2) + (W_3+h_3) \Rightarrow a$; (ponding)

Figure 48 Possible Cases associated with the low hump situation

4.3 Structure of the Program

The computer program developed for the simulation model is composed of five main consecutive steps, as shown in Figure 5.9. This section presents the outlines of each computational step with the selected computer subroutines.

4.3.1 The Input Data

The input data is divided into the three groups described below:

(a) Surface Roughness Data: This consists of the measured elevation traces of the original surface. The data variables of this group are:

YYP = a vector variable describing the elevation at all points on all elevation traces in sequence;

NPF = number of elevation traces;

NP = number of measurements on each trace;

DX = spacing between measurements;

TLEN = total length of the elevation trace.

(b) Physical Parameters: These are the variables describing the physical properties of the problem, used in erosion computations, namely:

UWT = unit weight of the soil, in kg/m^3;

DMLM = representative diameter of soil particles, in mm;

RN = Manning's roughness coefficient;

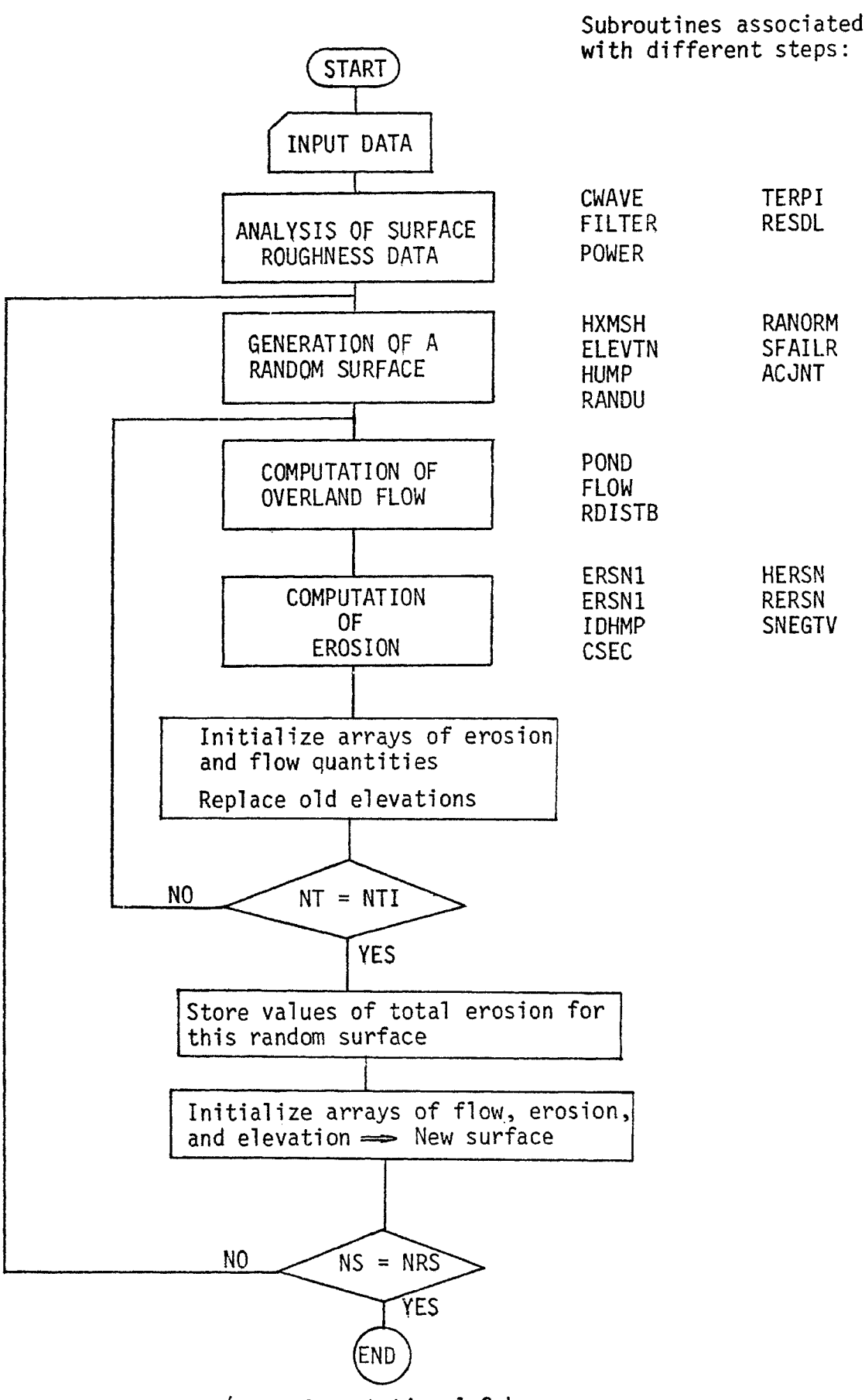


Figure 4.9 Computational Scheme

G = gravity acceleration, in m/sec^2;

SG = soil specific weight;

RO = water density, kg/m^3;

p = exponent of Kalinske's equation; see Equation (3.10);

ASR = soil constant, a_s, in erosion equation; see Equations (3.18) and (3.12); and,

ASH = soil constant, a_s, in interrill erosion equation; see Equations (3.23) and (4.12).

(c) Storm and Slope Data

NX = number of nodal points in the cross-direction of the underlying rectangular mesh, see Section 4.3.3;

NY = number of nodal points in the longitudinal direction of the underlying rectangular mesh;

SLOPE = the average slope of the test area, in degrees;

RNL = rainfall intensity in mm/hr;

RNF = runoff coefficient, See Section 4.1.1;

TI = length of time interval, in minutes;

NTI = number of time intervals; and,

NRS = number of random surfaces to be generated. A sample of size = NRS can then be used in any further statistical analysis.

4.3.2 Analysis of Surface Roughness Data

The input to this step is the surface roughness data. The analysis is conducted in the following sequence:

1. For each of the elevation traces, remove the mean (Subroutine FILTER), then compute Fourier coefficients (Subroutine POWER). Fourier coefficients are computed using the method of Fast Fourier Transform, which is documented in the computer package called IMSL (15), and is called by Subroutine POWER.

2. Compute the average coefficients for each wave component (Subroutine CWAVE).

3. From the range of waves of length $\leq$ 30 cm, pick up the wave component with maximum contribution to total variance. Then compute the residuals from each trace (Subroutine CWAVE).

4. Compute the mean and the standard deviation of the residuals from each trace (Subroutine RESDL).

5. Compute the average mean and standard deviation for all traces (Subroutine CWAVE).

4.3.3 Generation of the Random Surface

The input to this step is the amplitude, AMP, and the wavelength, WL, of the basic wave, plus the mean and the standard deviation of the residual data.

The computational procedure for generating a random surface is described as follows:

1. Compute the nodal coordinates of a rectangular mesh NX x NY with the mesh size as indicated in Figure 4.10 (Subroutine HXMESH).

2. Assign codes to nodal points according to their location in the mesh. Points such as b are assigned code = 2, whereas points such as a are assigned code = 1. The remaining points of the rectangular mesh, such as c, are given code = 0. The hexagonal mesh is formed when points of code = 0 are eleminated, as shown by the solid lines in Figure 4.10.

3. Compute the elevations of the plane surface at nodal points using the value of SLOPE for the surface gradient (Subroutine ELEVTN).

4. Superimpose the basic wave on the plane surface according to the given values of amplitude.

5. Using Subroutines RANORM and RANDU, draw a random number for each nodal point and add it to the elevations obtained by Subroutine ELEVTN.

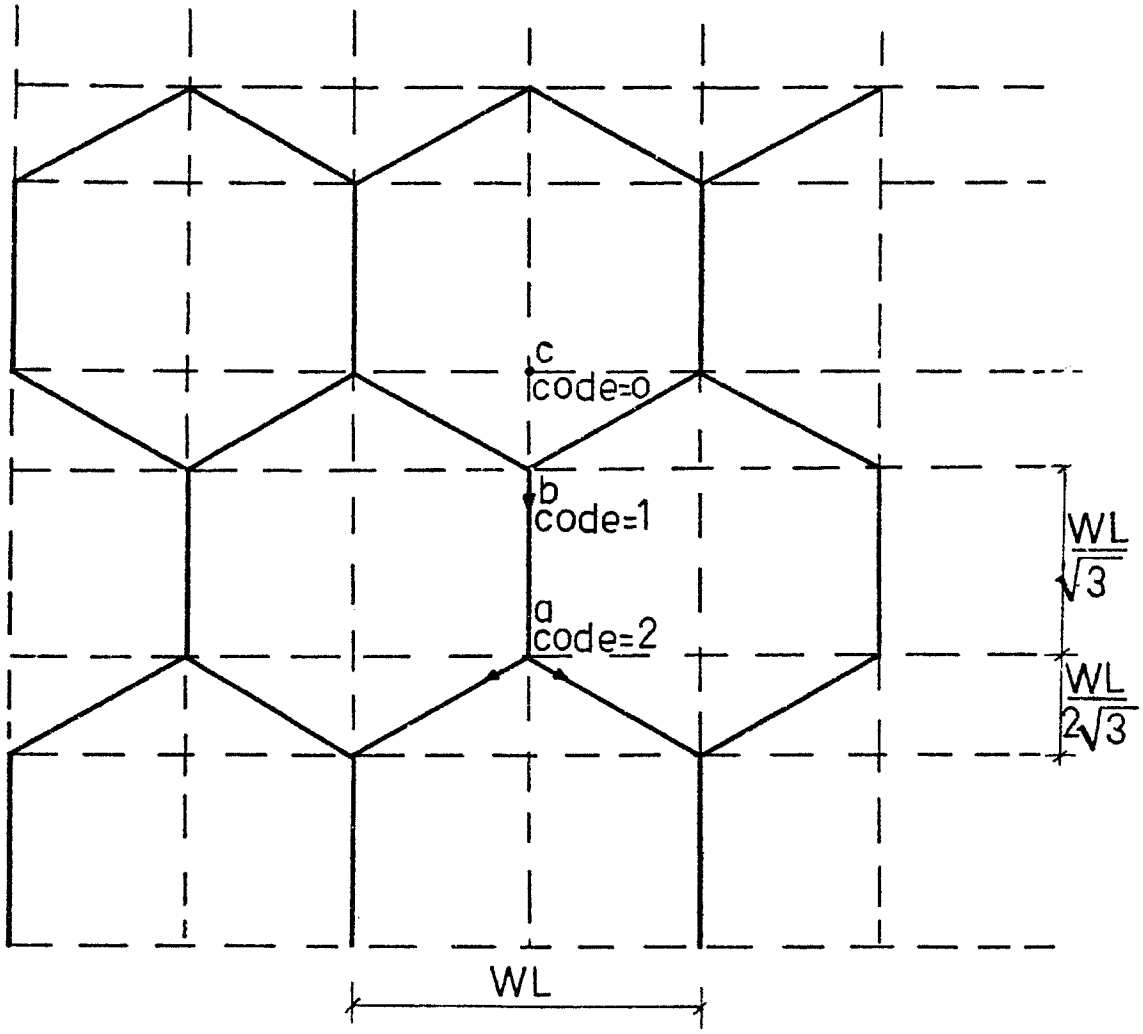


Figure 4.10 Construction of the Hexagonal Mesh

6. Draw another group of random numbers to randomize the elevations of the humps (Subroutine HUMP).

7. Check the stability of side slopes of all rill segments (Subroutine SFAILR). Criterion and mechanisms for this procedure are discussed in Section 4.2.3.

These steps generate the initial random surface, which is then subjected to overland flow and erosion.

4.3.4 Computation of Overland Flow

Based on the considerations described in Sections 4.1 and 4.2, the routing of overland flow is carried out for each time interval as follows:

1. Survey all rill segments to check for ponding along any path, on the basis of the mechanisms explained in Section 4.2.1 (Subroutine POND).

2. Compute the flow at each nodal point (Subroutine FLOW).

3. When low humps exist, revise flow computations on the basis of the mechanism explained in Section 4.2.4 (Subroutine RDISTB).

4.3.5 Erosion Computation

Given the elevation and the overland flow at every nodal point, the erosion in rill segments and over adjacent humps are computed. Rill segments whose upstream nodal point has code=1 are dealt with in Subroutine ERSN1. Rills whose upstream node has code = 2 are processed through Subroutine ERSN2. Computations for every rill segment are conducted in the following order:

1. For any rill segment, identify the surrounding humps which form its side slopes (Subroutine IDHMP).

2. Compute new values of bed slope and side slopes (Subroutine ERSN1, or ERSN1).

3. Determine flow depth and width in rill segment (Subroutine CSEC).

4. Compute erosion on side slopes of humps, or interrill erosion (Subroutine HERSN).

5. Compute rill erosion and the corresponding change in rill geometry on the basis of the mechanism explained in Section 4.1.2 (Subroutine RERSN).

6. Compute the total amount of soil eroded, and transported by the flow above a nodal point (Subroutine ERSN1 or ERSN2). If ponding exists along a rill path, the deposition mechanism described in Section 4.2.2 is applied.

7. Revise the distribution of sediment load at nodal points in order to account for the presence of low humps (Subroutine SNEGTV). The mechanism used in this step is explained in Section 4.2.4.

8. Calculate and store the total amount of sediment load received at nodal points at the bottom of the slope. This quantity represents the total sediment yield in a specific time interval.

9. Elevation of nodal points and humps are revised to account for erosion during the preceeding time interval. Arrays of flow and erosion are initialized, in preparation for the new values of the next time interval.

The computation steps explained in Sections 4.3.4 and 4.3.5 are repeated for successive time intervals until the end of the test period. Figure 4.11 shows a schematic representation of the relation between different subroutines.

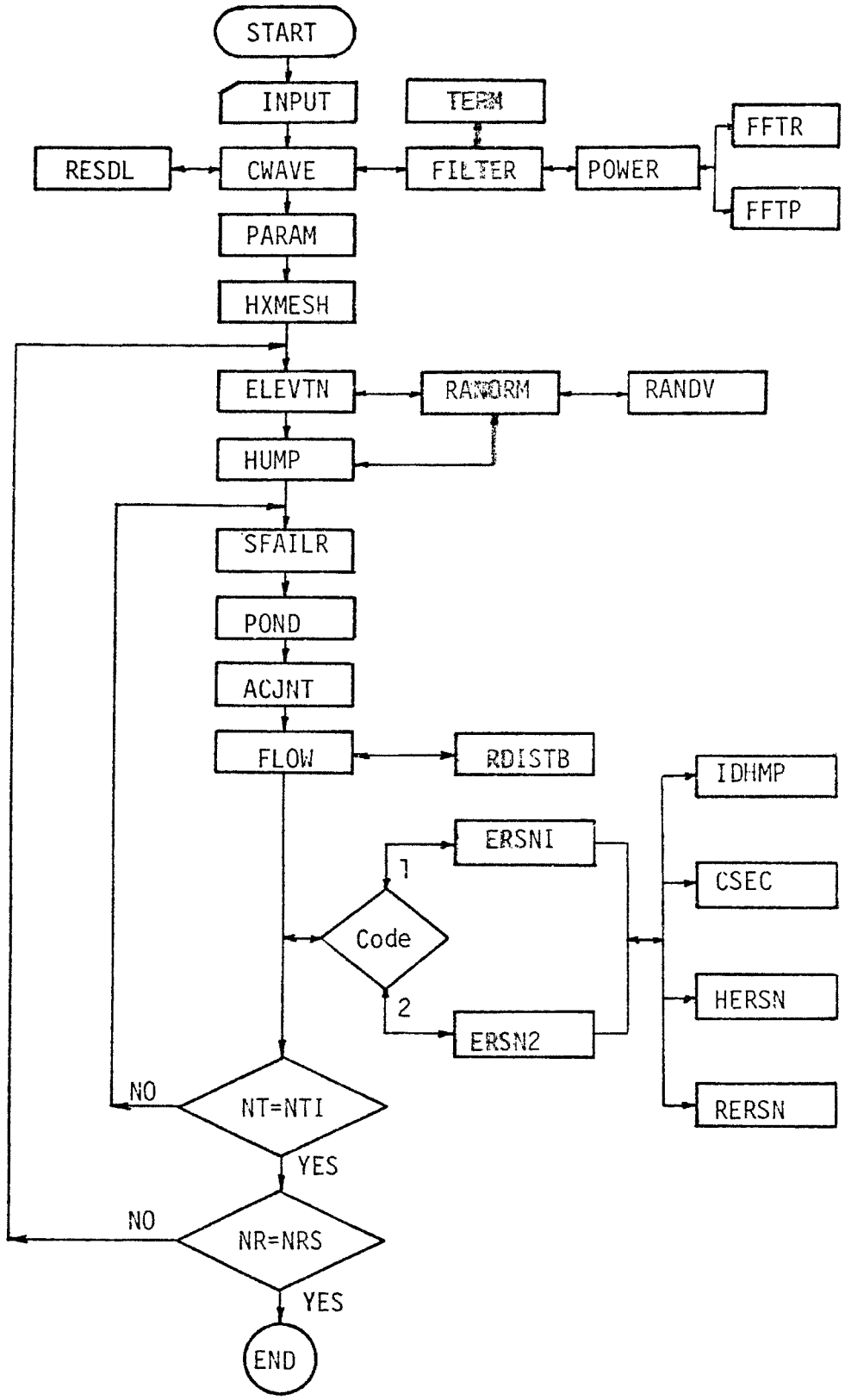


Figure 4.11 Schematic Representation of Model Subroutines

4.4 Sensitivity Analysis

This section considers the sensitivity of the model to the different parameters and factors incorporated into the model. The computational procedure of the computer program is long and thus requires a preliminary study to determine reasonable limits of time and space to which the model can be applied. Accordingly, the first part of the sensitivity analysis investigates the effect of the length of time interval and the dimensions of the test area on model performance.

The second part of this analysis examines the sensitivity of the model to the important parameters in erosion equations. Those are n, a_s, and p, which appear in Equations (3.8) and (3.12).

The last part of this chapter investigates the sensitivity of the model to randomness in the rill pattern.

In most of the cases studied, the criterion for judging the performance of the model is the shape of the curve relating the soil Erosion Rate, in $N/m^2/hr$, to time (ER vs. T). When relevant, we also use the relation between Rill-Interrill Erosion Ratio and time (R/I vs. T).

4.4.1 Geometric Limitations

The width of the hexagonal mesh element is determined by the spectral analysis of the surface roughness and is taken to be the length of the basic wave. For a given mesh size, we study the effect of the size of the test area on model performance. Tests were conducted using a rectangular area covered by a 20 x 50 mesh (i.e., NX = 20

and NY = 50, as defined in Section 4.3.1) and a 50 x 20 mesh. The results show large fluctuations in the ER vs. T curve for the 20 x 50 mesh.

A closer study of the numerical scheme indicated that this phenomenon is related to ponding. If the width of the test area is small, then ponding at any rill segment, especially the ones near the bottom of the slope, causes a significant drop in the ER vs. T curve. Then, in subsequent intervals, when deposition elevates a point and removes the ponding situation, the amount of sediment reaching the bottom rises.

The ER vs. T curve for a 50 x 20 mesh for exactly the same conditions has much smaller fluctuations. To keep the fluctuations small, subsequent runs are conducted using a 65 x 30 mesh.

4.4.2 Sensitivity to Time Interval

The study of the effect of the length of time interval is important in dynamic simulation models. Results of calculations with time intervals ranging from 2.0 to 360 minutes indicate a significant change in the shape of the ER vs. T curve with increasing time interval. The erosion rate at any time is larger for shorter intervals. This is attributed to the change in side slopes after slope failure and the effect of updating the elevations after each time interval.

To avoid excessive computation costs, a time interval of 10 minutes is used in the rest of the study. The computed erosion rate is about .80 of that for the smallest time interval of 2 minutes.

4.4.3 Sensitivity to Parameters in Erosion Equations

The erosion model approximates the flow in rills and over interrill areas by a uniform flow, as expressed by the Manning equation (Equation 3.5). Therefore, it is important to investigate the effect of Manning's coefficient on the results of the model. Other important parameters in the erosion models are the exponent, p, and the constant, a_s, in Kalinske's bed load equation (Equation 3.10). However, a_s for rill erosion may be considerably different from a_s for interrill erosion. Therefore, ASR is used to denote a_s in the rill erosion equation, (Equation 3.18) and ASH is used in interrill erosion equation (Equation 3.23).

Table 4.1 indicates the values adopted for different parameters in the sensitivity analysis.

4.4.3.1 Coefficient n in Manning's Equation

The value of n is strongly dependent on the roughness of the surface over which water flows. Values of n, for a variety of cases, are reported by Chow (4). However, because of the small scale at which the erosion problem is analyzed, it is very difficult to choose the appropriate values of n. To test the model, values of 0.02, 0.03, 0.04 and 0.05 were used for n. As shown in Table 4.1, when other parameters were tested, n was taken to be 0.04.

TABLE 4.1 PARAMETERS USED IN SENSITIVITY ANALYSIS

Parameters Fixed During the Analysis	Parameters Varied During the Analysis*
NX x NY = 65 x 30	N = 0.02, 0.03,(0.04), 0.05
RNL = 64 mm/hr	ASR = 200, 300, (400), 500
RNF = 0.5	ASH = 10, (20), 30, 40
TTIME = 6 hours	P = (1.5), 1.75, 2, 2.5
TI = 10 min.	SLIMIT = 1.1, 1.2, 1.3, (1.4)
D = 0.01 mm	
SLOPE = $20^{0} \simeq 37\%$	
SSTART = 1.1	

* Values in parentheses are used when testing other parameters.

The ER vs. T curves for different values of n are shown in Figure 4.12. In general, the erosion rate increases with the increase of n. The fluctuation of the ER vs. T curve increases with n. This can be attributed to the effect of the ponding mechanism, since with higher erosion rate, associated with increasing n, the flow carries more sediment and ponding becomes more important.

The effect of Manning's coefficient on the rill-interrill erosion characteristics is shown in Figure 4.13 This effect varies with time during the test period. At late times, when erosion is sufficiently accelerated, higher values of n result in higher rill-interrill erosion ratio. The reason for this is explained below.

The erosion mechanism as described in Section 4.1.2 directly relates the erosion of the bed of a rill with the erosion from its sides. That is, if a rill bed is lowered by a certain distance, the slopes of the sides are increased by a corresponding amount. But the increase in the slope of the bed is less than that of the sides because erosion lowers both ends of the rill segment, although by different amounts. Therefore, the rill erosion actually increases the interrill erosion of adjacent humps more than the rill erosion in the segment itself. Since rills comprise only a small fraction of the surface, the progress of erosion results in a continuous reduction in the rill-interrill erosion ratio.

After a time interrill erosion causes the side slopes to reach failure limit (SLIMIT). Subsequent interrill erosion will be significantly reduced, causing the rill-interrill erosion ratio to increase

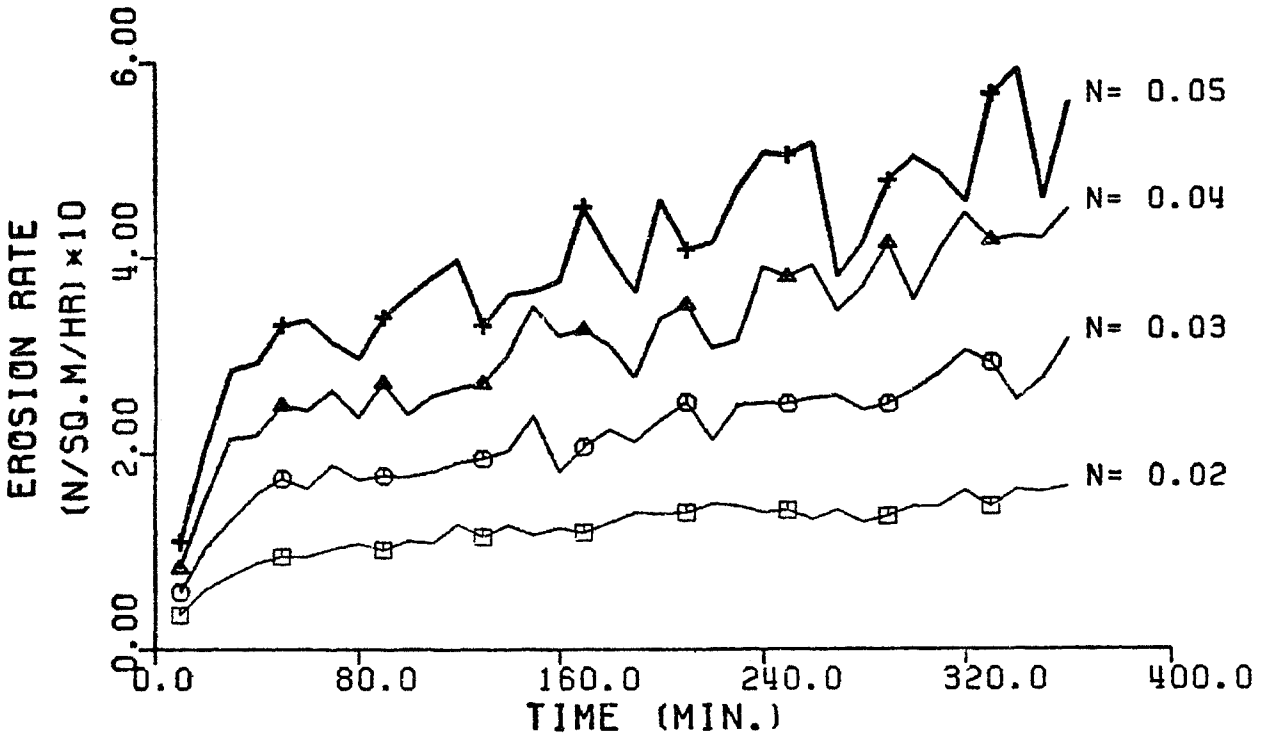


Figure 4.12 Effect of Manning's Coeff. on erosion rate

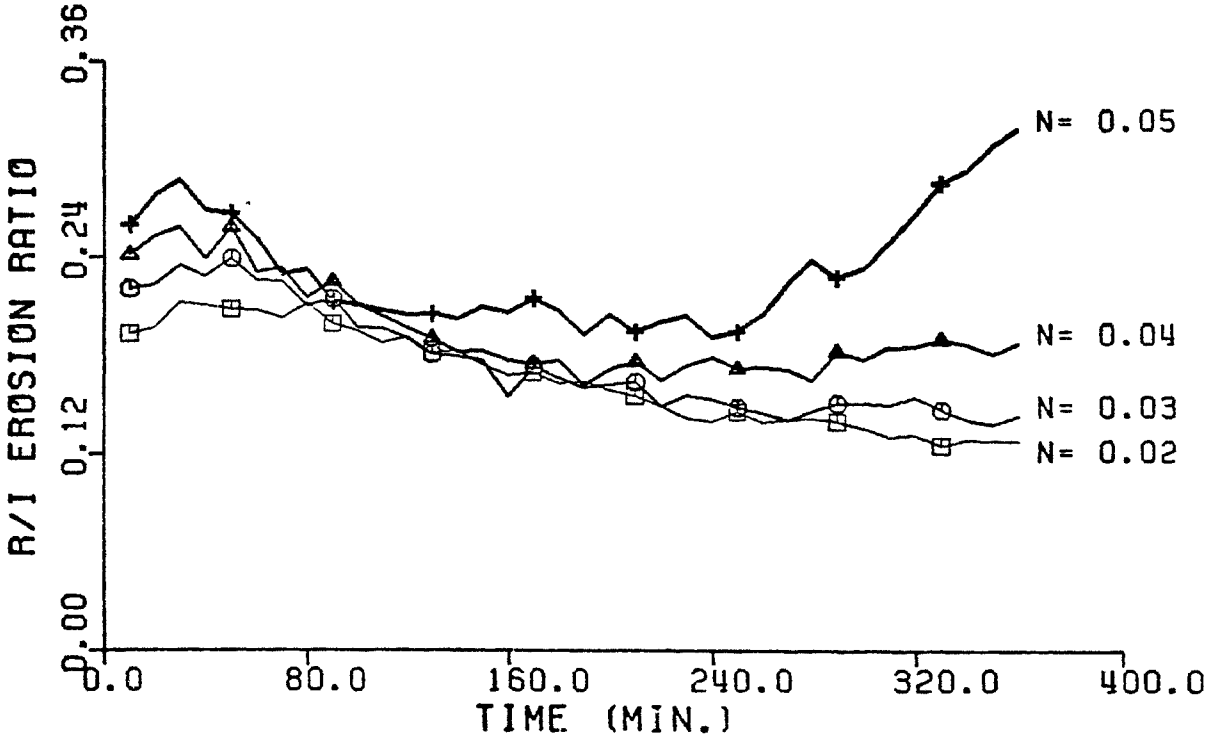


Figure 4.13 Effect of Manning's Coeff. on R/T Erosion ratio

for the rill segment in question. Thus, we can see that the overall R/I ratio will decrease with time until side slope failure begins to affect a large enough number of humps in every time interval. At this point, interrill erosion ceases to increase, while the rill erosion continues to increase, and the trend of the R/I vs. T curve is reversed. The time at which the R/I ratio begins to increase depends on parameters which control erosion. In this test, higher values of n result in greater erosion rates, and shorten the time to reach this point. We can see from Figure 4.13that the R/I ratio begins to increase at 240 minutes where n = 0.05. When the test period is extended for the case of n = 0.04, the R/I ratio begins to increase after about 380 minutes.

In summary, we find that, within the tested range, i.e., 0.02 to 0.05, the model is sensitive to Manning's coefficient. Its value affects both the total erosion rate, and the rill-interrill erosion ratio.

4.4.3.2 The Constant a_s

According to Komura (15), the value of a_s when rills and gullies exist (denoted by ASR), is about 300. For interrill erosion, a_s (denoted by ASH) takes on a value of about 30.

The sensitivity to ASR was tested for values equal to 200, 300, 400 and 500. When other parameters were tested, ASR was taken to be 400. It was found that the model is not sensitive to the value of ASR.

The second test used ASH values of 10, 20, 30 and 40. When other

parameters were tested, ASH was given a value of 20. The erosion rate generally increases with the increase of ASH. The maximum erosion rate for ASH = 40 is about three times that for ASH = 10.

4.4.3.3 The Exponent p

The parameter p is an empirical exponent in the Kalinski equation (3.10). For open channels, Kalinske and Brown (see ref. 31)suggest a value of 2 for p.

To investigate the effect of p on the model, erosion was computed for p values of 1.5, 1.75, 2.0, and 2.5. It was found that smaller values of p result in higher rates of erosion. The erosion rate is sensitive to p and increases about 10 times when p is reduced from 2.5 to 1.5. The R/I ratio is less sensitive but generally, smaller values of p produce higher rill-interrill erosion ratio. For example, at the end of the test, R/I ratio for p = 1.5 is twice as much as that for p = 2.5,

4.4.4. Sensitivity to Criterion of Side Slope Failure

The mechanism of side slope failure, although simple, is very important in erosion simulation over longer time periods. The two controlling factors are the upper and lower limits of the slopes, SLIMIT and SSTART, respectively.

The purpose of this test is to study the behavior of this model under different values of the quantity (SLIMIT - SSTART). To do so, SSTART was assigned a fixed value of 1.1, whereas SLIMIT varied from 1.1 to 1.4. The influence of this factor on the erosion rate is

shown in Figure 4.14. The sensitivity of the model to the quantity (SLIMIT - SSTART) is generally low, but it increases somewhat as the erosion progresses.

4.4.5 Effect of Randomness in Elevation

This part of the analysis is aimed at studying the sensitivity of the model to the randomness in elevations of nodal points on humps. Therefore, a comparison is made between the model results when randomness is included and when it is omitted in the slope surface.

The case when randomness is included can be represented by the results in Figure 4.14, described in the previous section. The test is repeated under the same conditions, except with the random component set equal to zero. The latter scheme results in a surface with identical humps. Furthermore, all rill segments emerging out of a nodal point of code - 1 will have a bed slope equal to the average slope.

Figure 4.15 shows the relationship between the erosion rate and time for the uniform surface. In comparison with the results in Figure 4.15, we can see that the uniform surface produces higher rates of erosion at all times. The erosion rate increases nearly uniformly with time, with little or no fluctuation, depending on the value of SLIMIT. It seems obvious that the non-random case presents a surface with less "obstacles", and with no possibility of ponding along rill paths. Thus, water flows downslope in identical channels, resulting in uniform erosion of the surface. It is therefore possible

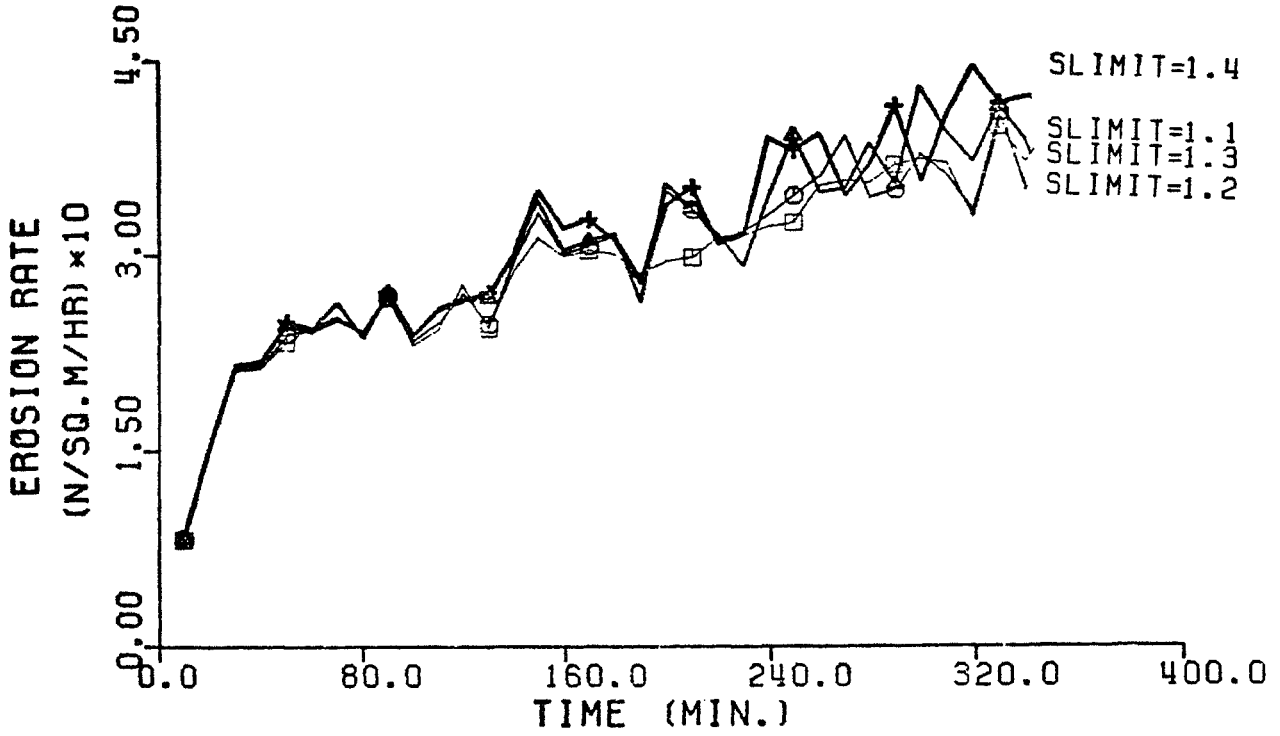


Figure 4.14 Effect of the factor SLIMIT on Erosion Rate

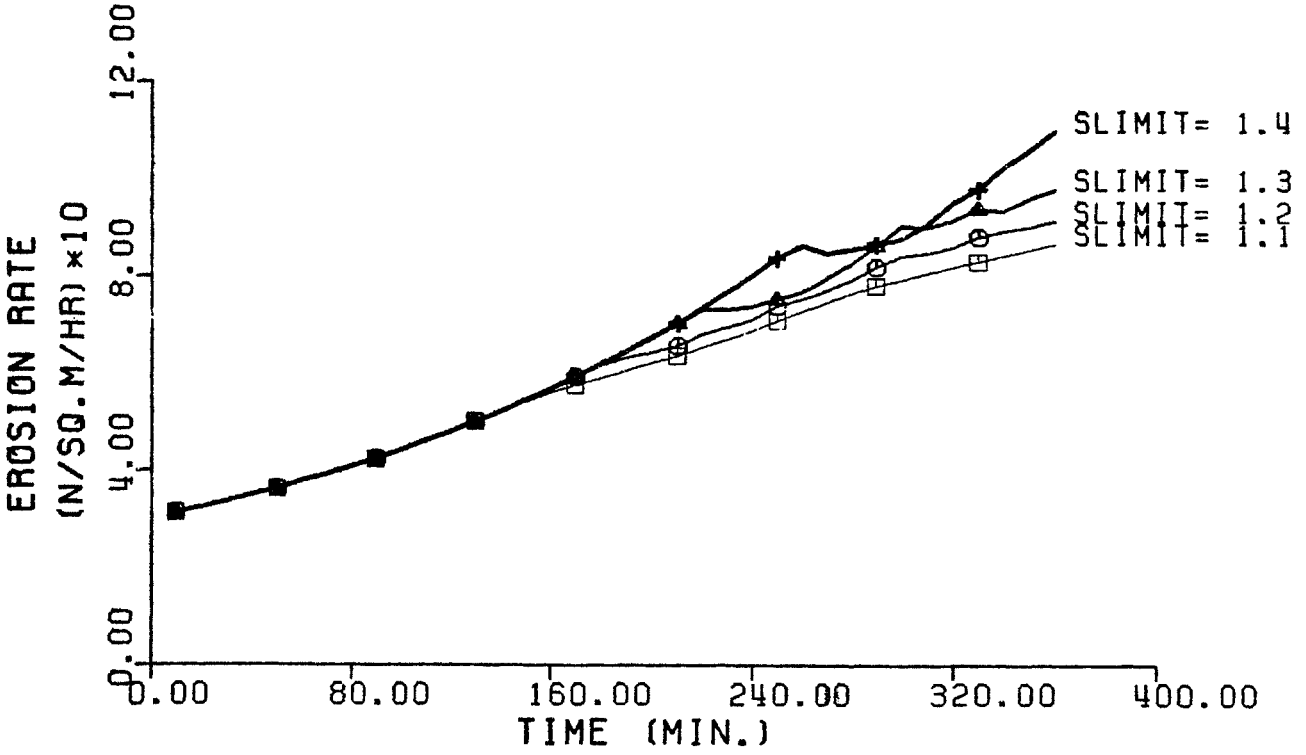


Figure 4.15 Effect of randomness in elevation on erosion rate

to conclude that the randomness in elevations of the surface points has a considerable effect on the results of the model.

Further examination of the shape of the erosion rate curve provides better understanding of the way the mechanism of side slope failure operates. Figure 4.15 represents the results of four identical surfaces, but with different limits for the side slope failure. In the case of SLIMIT = 1.1, the erosion rate increases uniformly with time for a period of about 160 minutes. At this point, the side slopes of all rill segments reached the limit (SLIMIT), and the rate of interrill erosion remains the same with time. The total erosion rate, however, continues to increase, with a lower rate, due to the increase in rill erosion.

4.4.6 Effect of Randomness in Rill Pattern

As described in Section 2.2, the surface of a new soil slope consists of many humps and depressions. The actual path of overland flow is quite irregular, at least in the early stages of erosion, before well-defined master rills are formed (Horton, 12).

The hexagonal rill pattern is an important simplification. Hence, an attempt was made in this section to compare the performance of the model with that of a model using a random rill pattern.

The random rill pattern is generated according to the procedure described in Section 2.4.2, using the results of zero-crossing analysis. The amount of soil eroded at any point is directly dependent on the flow characteristics at this point. Therefore, instead of comparing amounts of soil eroded, we can use the flow as a basis for comparison.

Consequently, the problem is reduced to a comparison between water quantities flowing in different rill segments. Such comparison is far from being complete, yet it serves as an indication of the potential effect of the rill pattern.

The random surface used in the comparison covers an area of NX = 15 and NY = 8, with an average slope of 20 degrees. For the random rill pattern, the surface was generated according to the procedure described in Section 2.5.. For simplicity, we assume a unit amount of water to be drained into each rill segment from adjacent humps. At nodal points, the flow is also divided between different segments according to the rules described in section 4.1.1.

Because the rill flow increases downslope, we must compare the flow in rill segments at the same position on the slope. Two samples in each surface are selected to make the comparison. The first sample consists of the rill segments of the 4th "row" from the top. The second sample consists of rill segments in the 6th "row". The location of samples are shown in Figures 4.16 and 4.17. Each sample contains 14 segments.

Figures 4.18 and 4.19 show the distributions of the flow obtained in each case. The results indicate that the null hypothesis, Ho, that the two samples belong to the same distribution, is rejected in the test on the 4th row. The same hypothesis, however, is accepted in the other test. The significance level in both tests is 0.05. It can be seen from Figures 4.18 and 4.19 that the distribution of rill flow using unidorm rill pattern has larger variation. It is not possible, however, to draw more specific conclusions about the overall

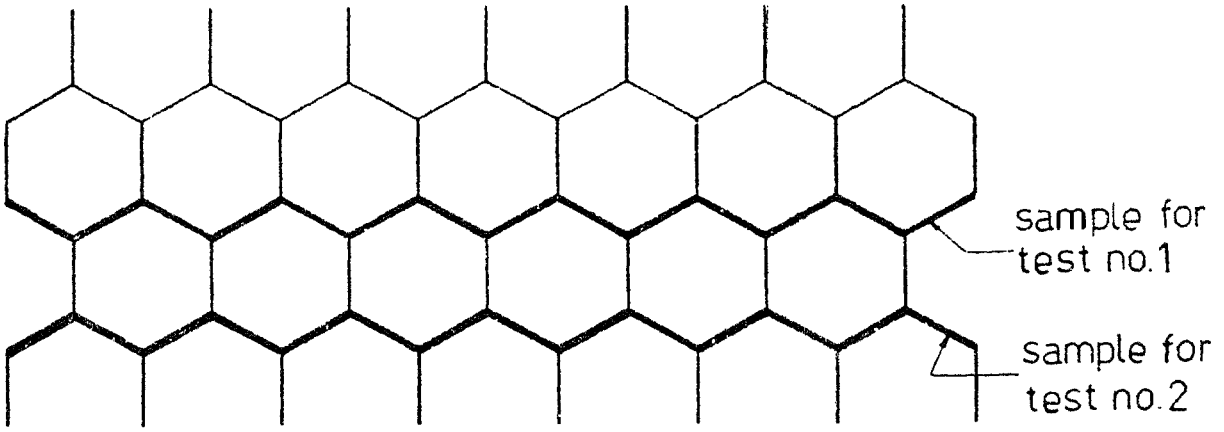


Figure 4.16 Test Samples from Uniform Rill Pattern

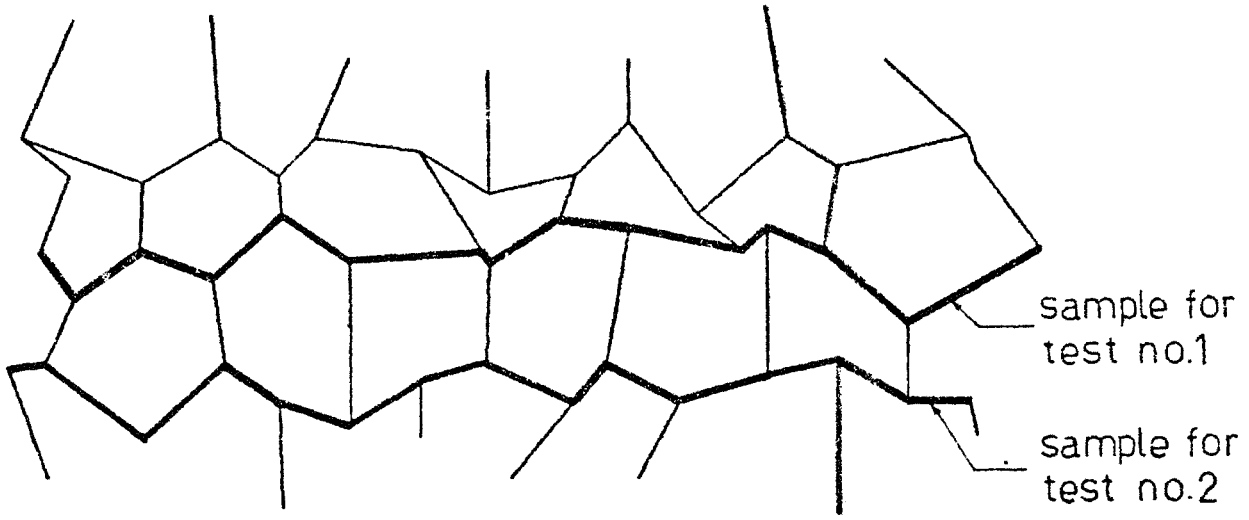


Figure 4.17 Test Samples from Random Rill Pattern

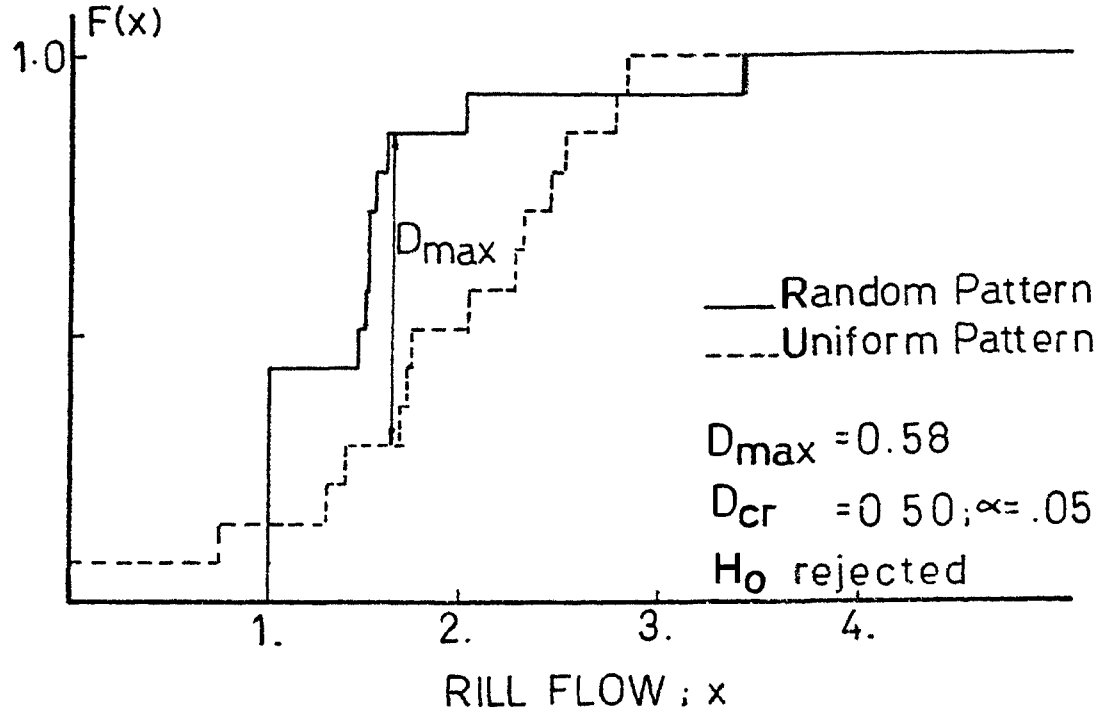


Figure 4.18 Effect of Rill Pattern Randomness on Flow; Test no. 1

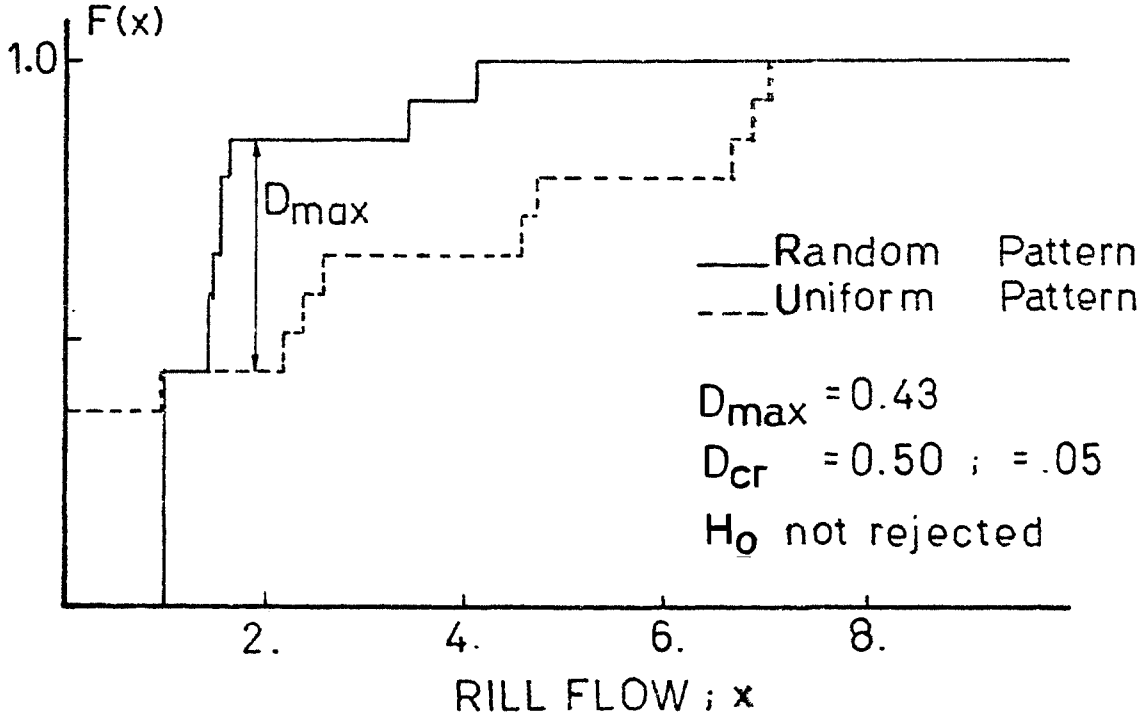


Figure 4.19 Effect of Rill Pattern Randomness on Flow; Test no. 2

effect of randomness in rill patterns on the model performance.

4.5 Concluding Remarks

The simulation model described in this chapter represents a simplification of the real process. The sensitivity tests have shown that the erosion rate is very sensitive to Manning's coefficient n and the parameter p in Kalinske's equation. Thus refinement of the erosion model would rely heavily on improvements in basic understanding of overland flow and sediment transport.

The most important characteristic of the model is the attempt to account for the randomness of rill flow caused by random surface roughness. The auxilliary mechanisms of ponding and low humps add to the randomness. Beginning with the mesh shown in Figure 4.20(a) without any random component on the surface elevations, the cross section would be A.A. When the random component of elevation is imposed, profiles such as those in Figure 4.20(c) and (d) may be obtained. In the first, the random components alter the heights of points on the profile, yet the original rill pattern is basically the same, with minor differences only in the size of the rills. On the other hand, if some points such as 3 and 7 have relatively large negative random components, low humps are created and this results in a different rill pattern, as shown in Figure 4.20(d). Thus the uniform hexagonal mesh serves only as a reference frame for computations and does not impose a fixed rill pattern. The fact that the flow for the hexagonal rill pattern has a larger variance than that for the random rill pattern suggests that the hexagonal pattern does not impose serious restrictions on the flow pattern.

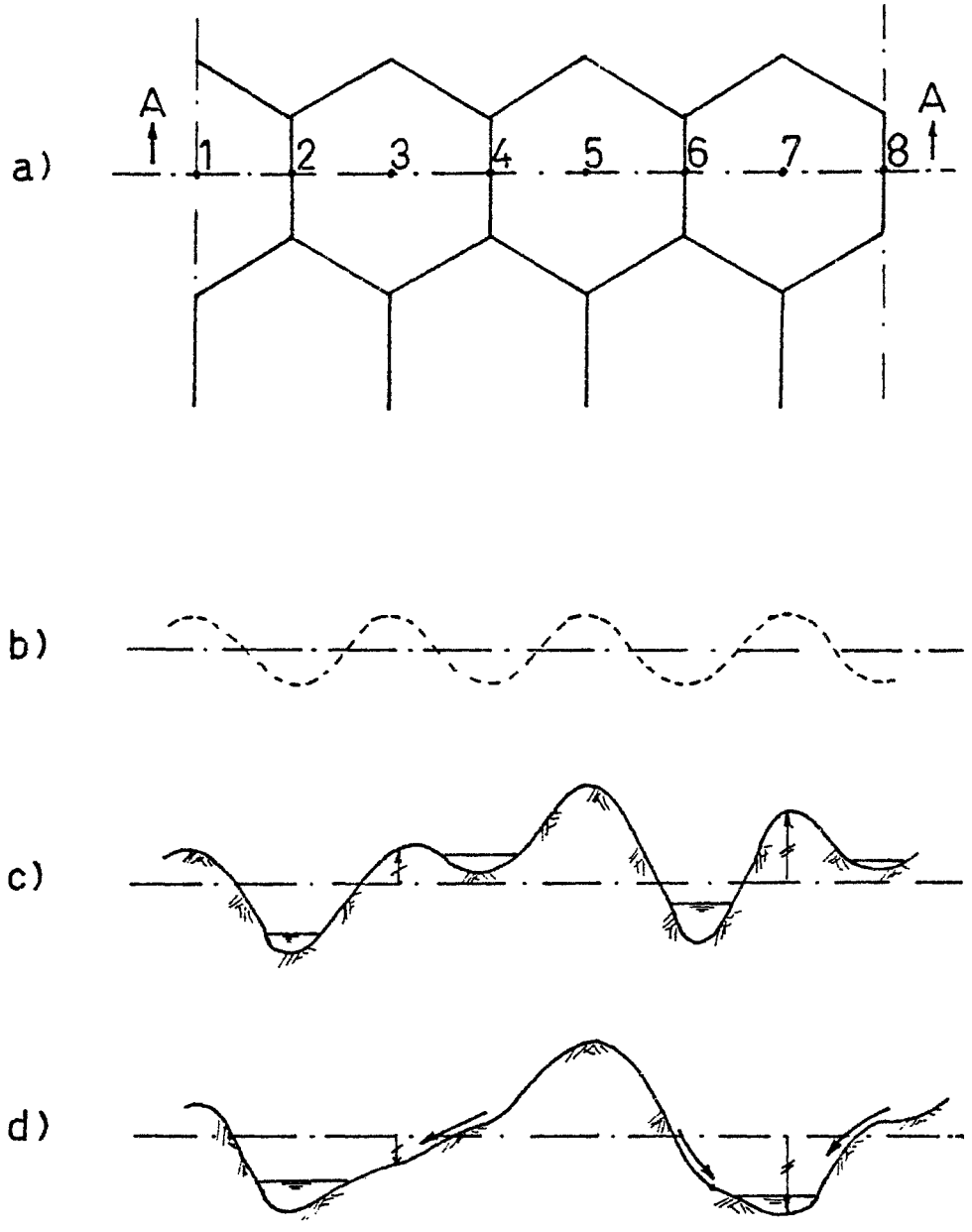


Figure 4.20 Irregularity in Generated Surfaces

5. MODEL PERFORMANCE

The simulation model was tested by comparison of the model performance with results of field experiments. However, the data obtained in most field studies are not adequate to allow detailed comparison between model and observed performance. Hence only order-of-magnitude comparisons could be made. One such case is described in Section 5.1.

An evaluation of the general characteristics of the model can be made by studying the influence of physical conditions on predicted erosion. The most important physical conditions are slope gradient, slopw length, and rainfall intensity. There is plenty of empirical evidence on how these conditions influence erosion. Hence a general comparison can be made to see if the model performance is qualitatively in agreement with empirical knowledge. This is described in Section 5.2.

5.1 Comparison with Field Measurements

Erosion measurements from highway embankments were used to compare with model performance. Barnett et al. (1) conducted field experiments at four different locations using rainfall si-ulators. At each location, seven plots with different treatments were prepared; one of these was left with a bare surface. Each site was graded to 2½:1 slope, seeded, rototilled, and then firmed with a cultipacker. At two of the four locations, the soil was classified as clay. The soil at the other two locations was classified as sandy clay loam.

The test storm was applied at an intensity of 6.25 cm per hour in two increments of 20 minutes each. The first increment, 3.13 cm in 30 minutes, corresponds to a one-year frequency storm; the entire test represents a 10-year frequency storm for the geographical region of Georgia.

Among the many parameters and measurements that are needed as input data to the model, some are common for slope erosion problems. These include ASR, ASH and p, and the constants describing the properties of water. On the other hand, the representative size of soil particles, the Manning's coefficient, and the surface roughness measurements are unique characteristics that must be determined for each site. Since much of the input data are not available for the test plots, it was necessary to assume reasonable values and use these for the calculations.

It is not surprising that no information about the surface roughness was reported in the paper by Barnett et al. With due reservations, the roughness data obtained from Wooster, Ohio, which has been analyzed in Chapter 2, was used here to represent a well-cultivated surface.

Since the field study was not concerned with comparing flow and erosion with any theoretical model, no estimate of Manning's coefficient, n, was presented. Use was made of the results of the investigation by Ree et al. (30) on the value of n in overland flow. Values as high as 0.3 were reported in their study for poor-cover conditions. For the bare surface in question, computations are made for a range of n from 0.025 to 0.2.

According to Foster and Meyer (8), clay particles are detached by rainfall as aggregates. These aggregates move along the bottom of the rills as cohesionless particles. The previous consideration is the basis for the choice of the values of the soil particle representative diameter, D, in the two types of soils. For the plot classified as clay, the reported gradation is 39% sand, 27% silt, and 34% clay. The clay particles in the USDA classification have a diameter of less than 0.002 mm. Therefore, to represent the clay aggregates and to allow for the non-aggregated sand and silt, the value of D = 0.01 mm was selected as the median diameter. For the second plot, with the gradation of 57% sand, 17% silt and 26% clay, a value of 0.05 mm was chosen for D.

Using a time interval of 2 minutes, the total soil loss at the middle, and at the end of a 60-minute storm period was computed. The computed soil losses for the two sites are shown in Figures 5.1 and 5.2. The results indicate that in order to achieve soil losses comparable to the measure values, the Manning's coefficient n should be around 0.085 for the clay site and over 0.2 for the sandy clay site. For a bare slope, those n values seem too high when compared with the estimates by Ree et al. (30). However, the values of n for overland flow in general, and for bare slopes in particular, are not yet well established. Hence, the discrepency is not considered conclusive.

It is also possible that the model underestimates the soil loss, because of the approximation used in the side slope failure mechanism, (Section 4.4.2) or because of incorrect values of ASH (Section 4.4.3.2) or P (Section 4.4.3.3). Thus, it is difficult to determine

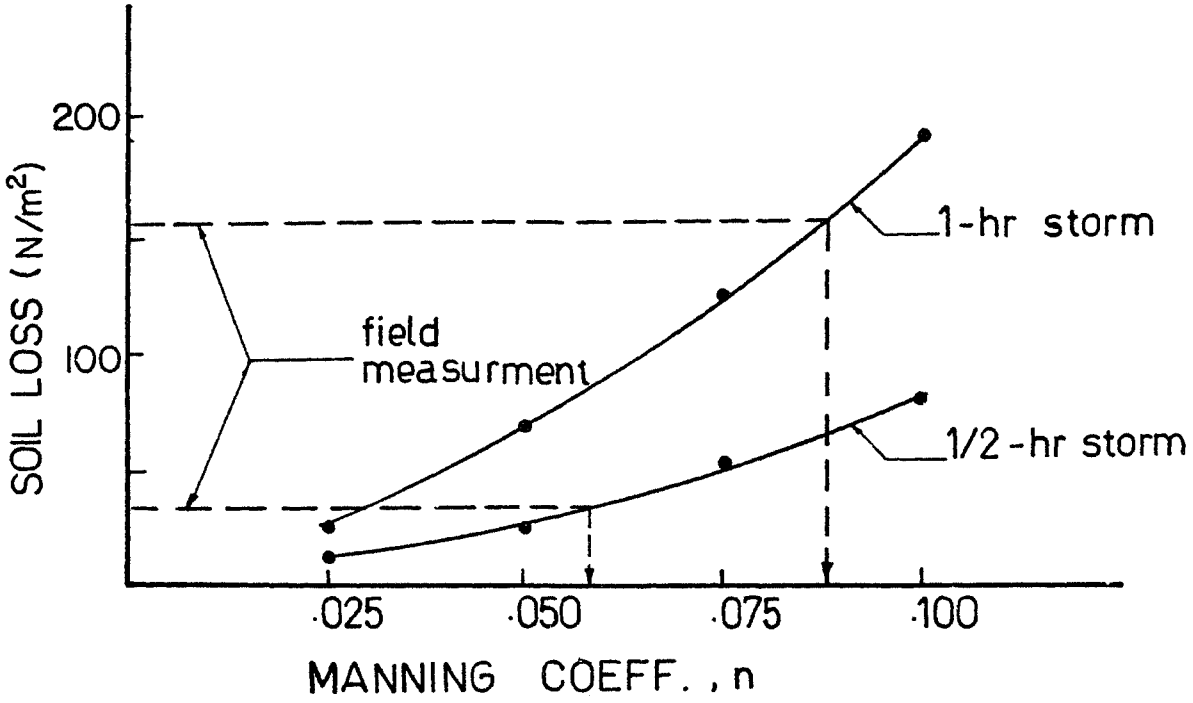


Figure 5.1 Soil Loss from the Clay Site *

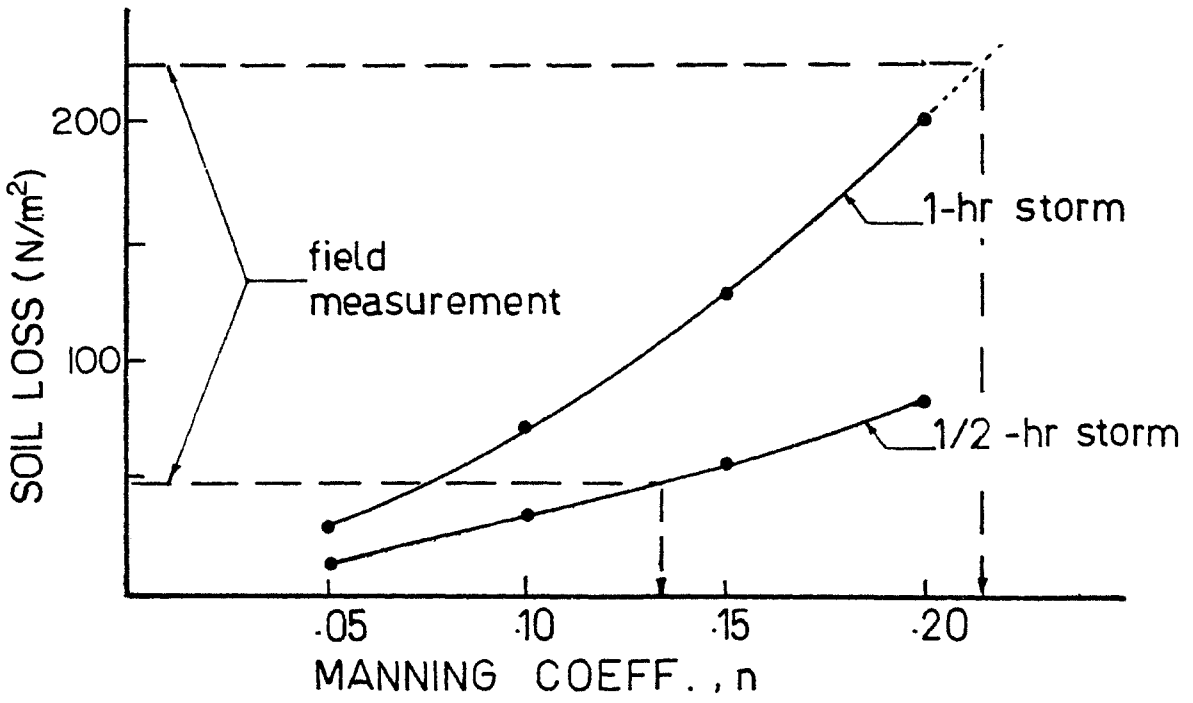


Figure 5.2 Soil Loss from the Sandy Clay Site *

* Model parameter ASR, ASH,P,SLIMIT are equal to values in ( ) in table 4.1

the specific source of discrepancy between the field measurements and the model results, because of the factors discussed in the introduction to this chapter. Therefore, it seems inevitable that a proper verification of the present model requires specific surface preparation and measurements.

5.2 Influence of Physical Conditions

5.2.1 Effect of Slope Gradient

The slope gradient of a soil surface is one of the most important facotrs which control erosion. Investigators, since the earliest erosion studies, have always attempted to determine the relation between the slope gradient and the erosion. Experimental as well as theoretical studies agree that soil erosion increases with slope gradient. A unique relation, however, has not been established (see ref., 18).

To study the effect of slope gradient on the model predictions, the erosion rate was computed for four plots with slopes of 5, 10, 15 and 20 degrees. Figure 5.3 shows the change of erosion rate with time for the four cases. The results indicate that steeper slopes result in larger erosion rates. The relation between slope gradient and erosion rate is time-dependent, as shown in Figure 5.4. This behavior may provide a possible explanation for the differences in the results of experimental studies on the effect of slope gradient on the erosion rate.

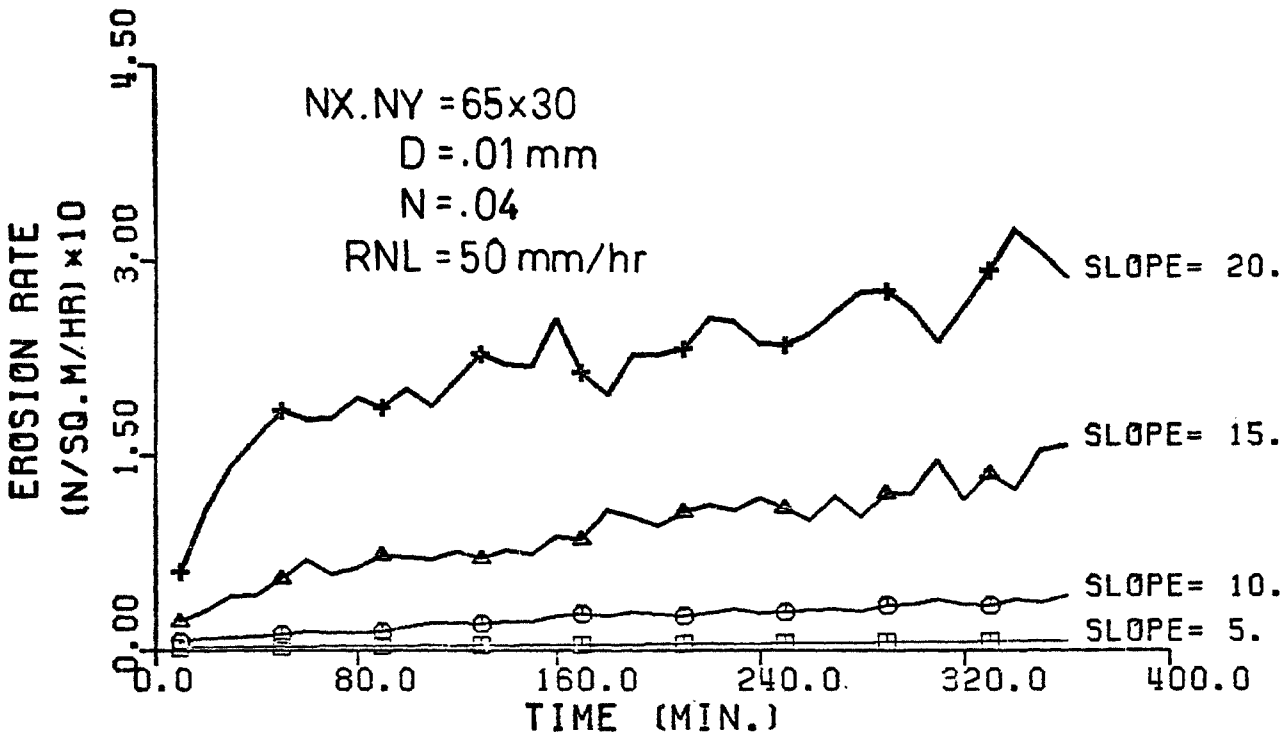


Figure 5.3 Effect of slope gradient on erosion rate

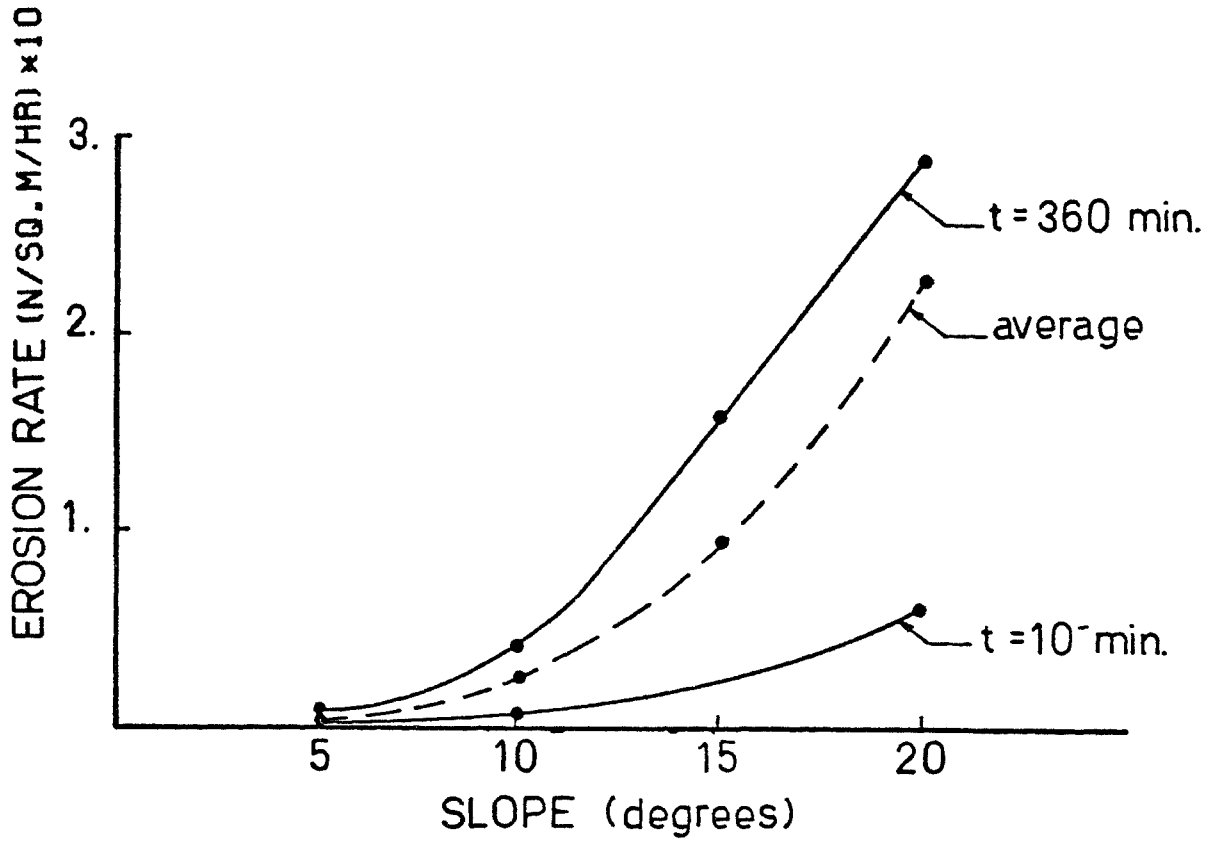


Figure 5.4 Effect of time on the slope gradient - Erosion rate relation

5.2.2 Effect of Slope Length

Since the overland flow tends to increase downslope, longer slopes result in longer and deeper rills and increased erosion. Therefore, the slope length can be expected to have a significant influence on the rill-interrill erosion features.

The relation between the erosion rate and time was computed for three plots of lengths 0.73, 2.29 and 3.85 meters. These values correspond to values of NY of 10, 30 and 50, respectively, as shown in Figure 5.5. The computed results are shown in Figure 5.5, and indicate that the erosion rate decreases with the increase of slope length. This behavior is not in agreement with empirical observations (see Reference 19). Determination of the reasons for this discrepancy requires additional investigation.

The effect of the slope length on the rill-interrill erosion is very important, since transport and detachment capacities of rills increase with distance downslope. Figure 5.6 shows the relation between rill-interrill erosion ratio with time for the same plots. It is clear that the contribution of rills increases with slope length. This means that rill erosion increases with distance down slope. Such behavior has been observed in many experimental studies (22,23,24).

5.2.3 Effect of Rainfall Intensity

Rainfall characteristics, such as intensity, angle of incidence, spatial, and temporal distribution, have variable impact on the erosion process. The present model takes into account only the rainfall intensity.

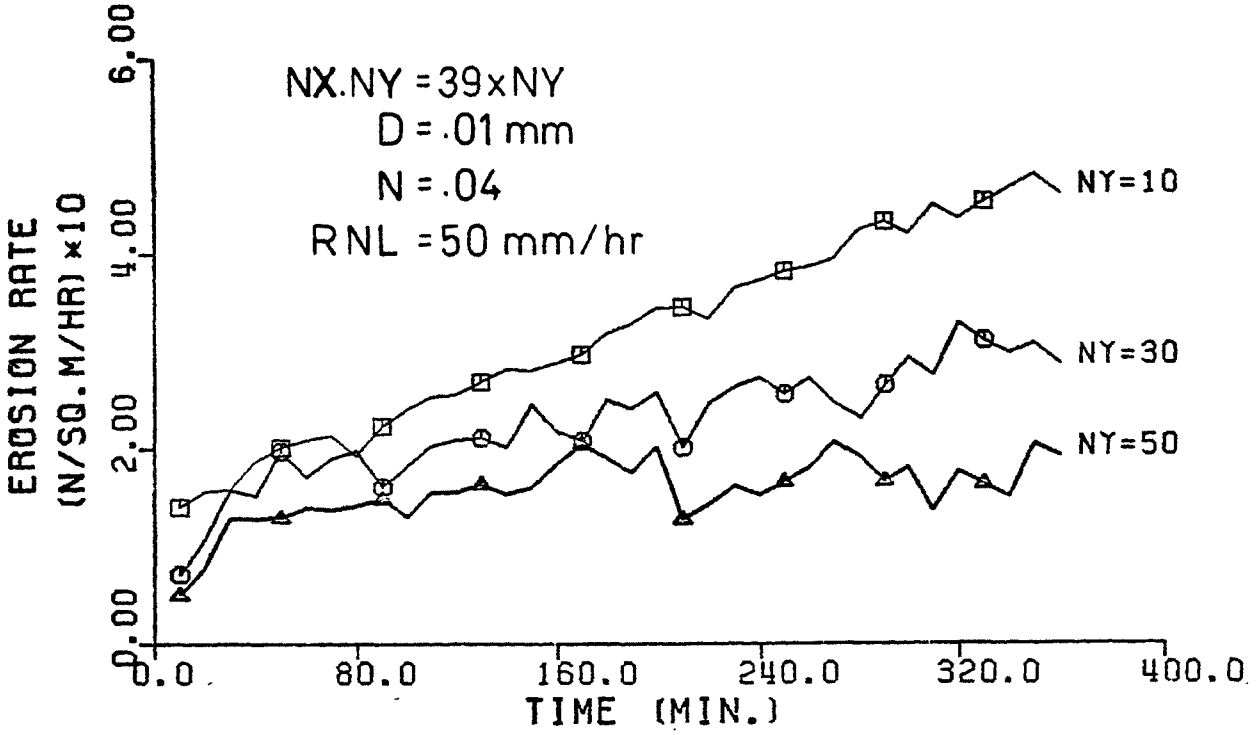


Figure 5.5 Effect of slope length on erosion rate

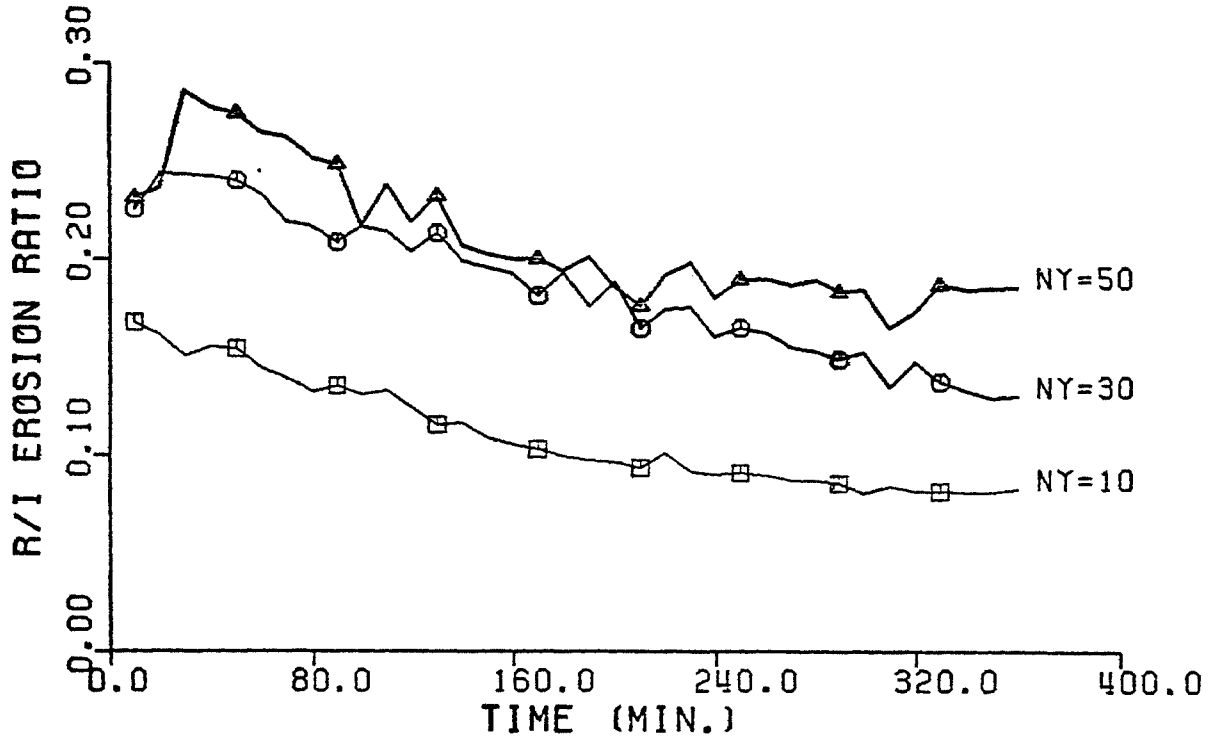


Figure 5.6 Effect of slope length on R/I erosion ratio

Three storms with rainfall intensities of 50, 25 and 12.5 mm/hour were considered, with rain periods of 3, 6 and 12 hours, respectively. This means that at the end of each test, all plots would have received the same amount of rainfall, which is 150 mm. Each of the three storms was applied to three plots with slopes of 5, 10 and 20 degrees, respectively. Results of the three storms are shown in Figures 5.7, 5.8 and 5.9.

As expected, storms of larger intensity result in higher erosion rates at all times. The relation between rainfall intensity and erosion rate seems to be dependent on the average slope gradient of the plot, as shown from Figure 5.10.

5.3 Evaluation of Eroding Surfaces

The purpose of this section is to illustrate the temporal and spatial changes in the surface geometry under erosion, as simulated by this model.

The original surface generated by the model is shown in Figure 5.11. Subsequent changes in the surface geometry caused by erosion are shown in Figures 5.12 and 5.13 at times 200, and 400 minutes, respectively. For the constant rainfall intensity of 50 mm/hr, the total amount of rain at the end of the test is 333 mm. The figures illustrate the growth of rill size with time and the effect of the random surface elevations on development of nonuniform rill pattern. The results are in qualitative agreement with observed rilling on slopes.

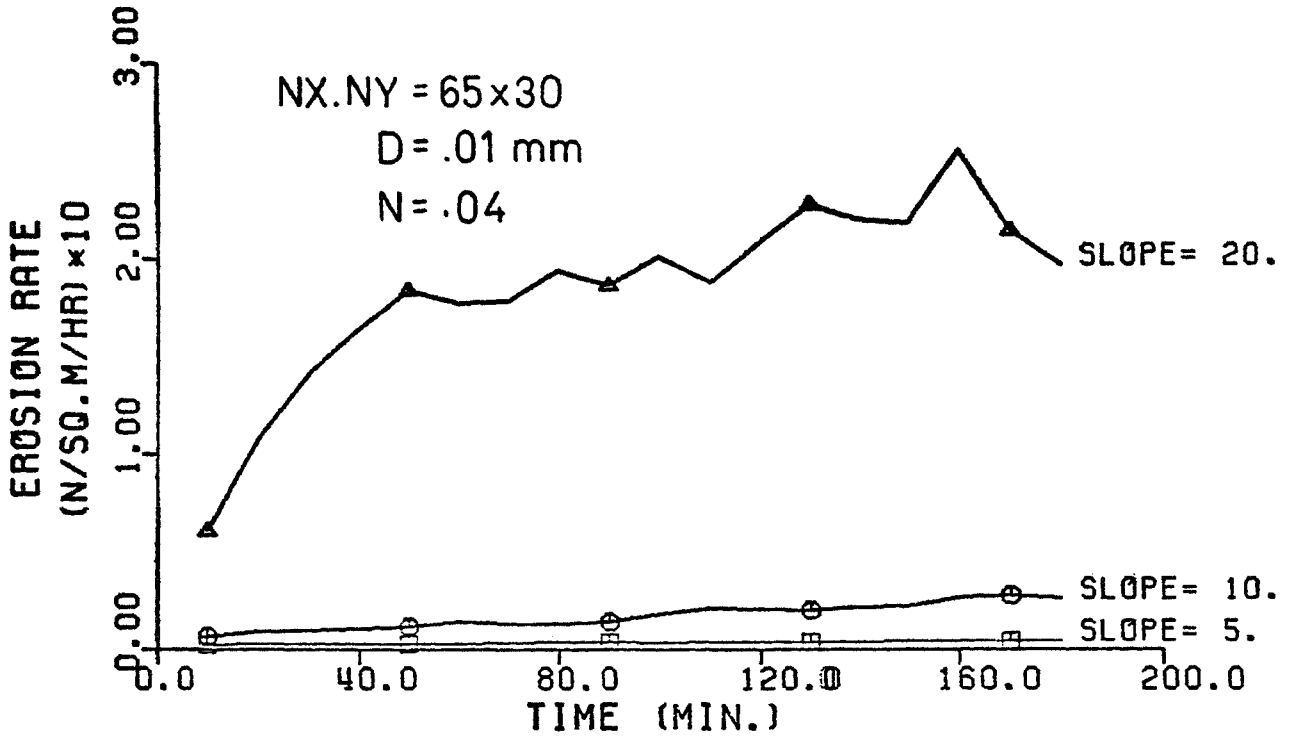


Figure 5.7 Effect of Rainfall intensity on erosion rate; RNL = 50 mm/hr

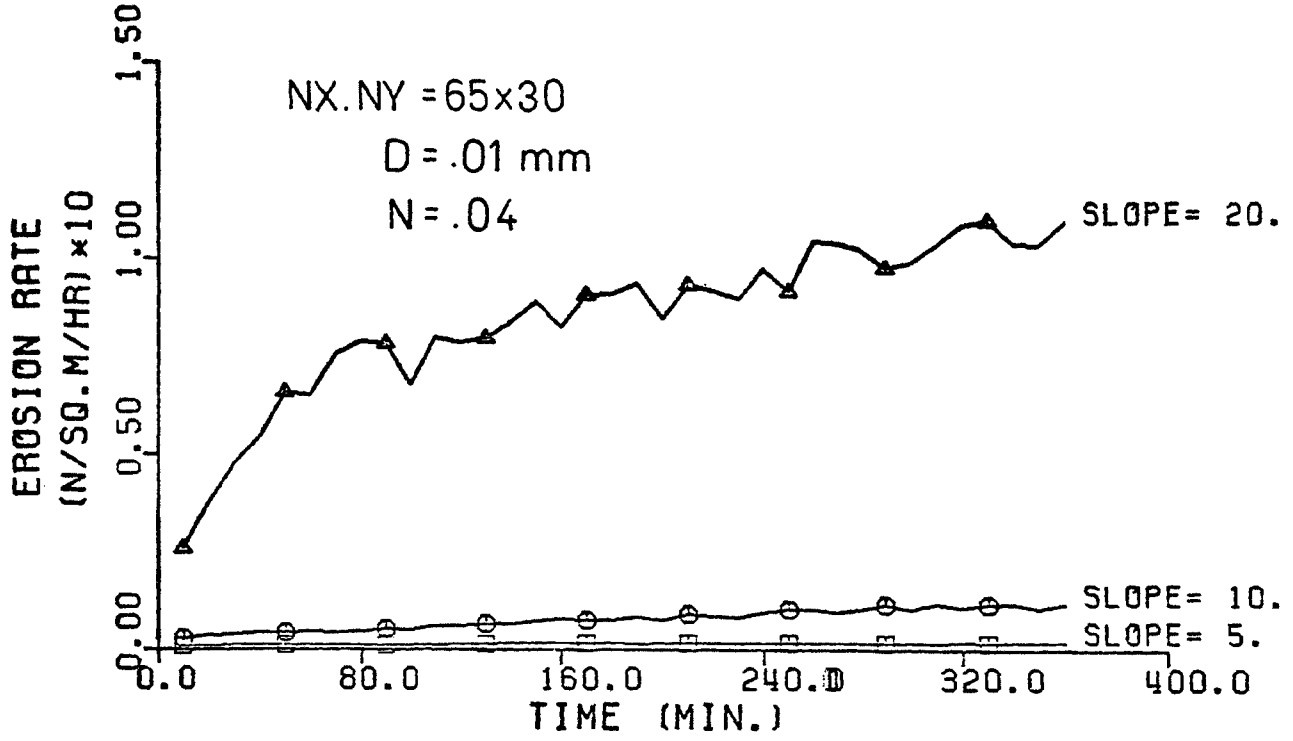


Figure 5.8. Effect of Rainfall intensity on erosion rate; RNL = 25 mm/hr

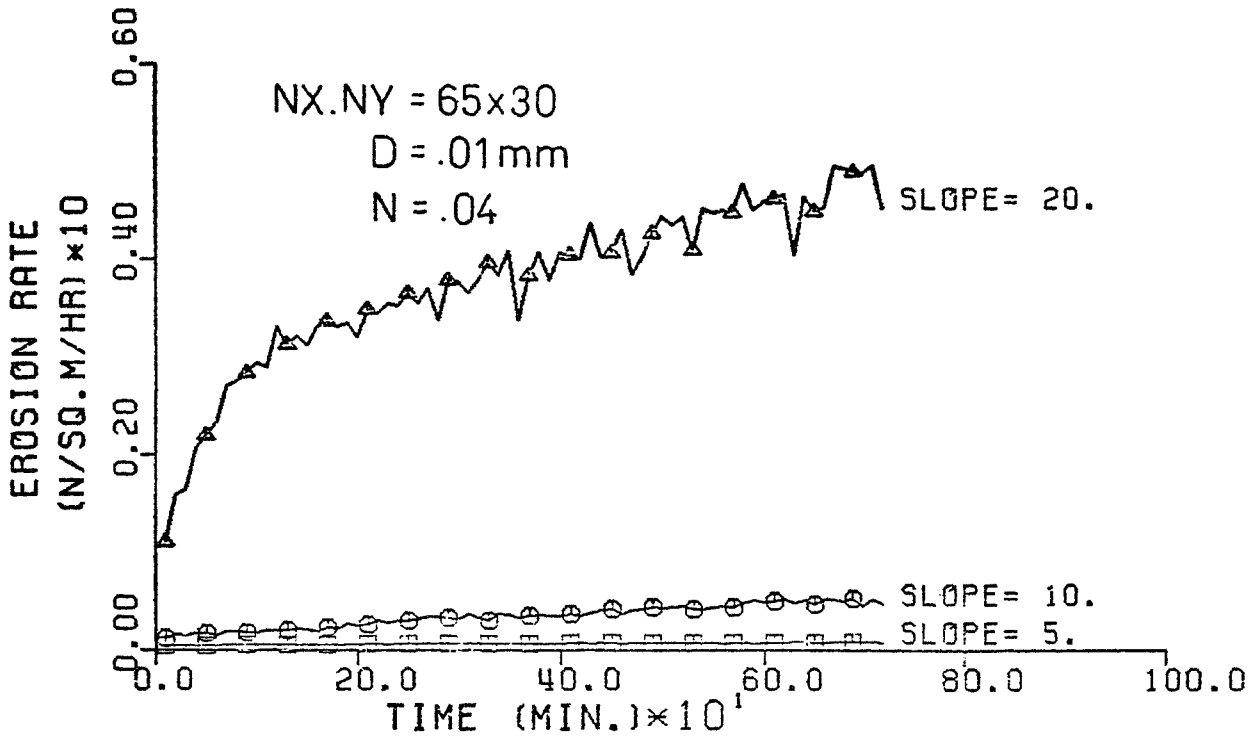


Figure 5.9 Effect of Rainfall intensity on erosion rate; RNL = 12.5 mm/hr

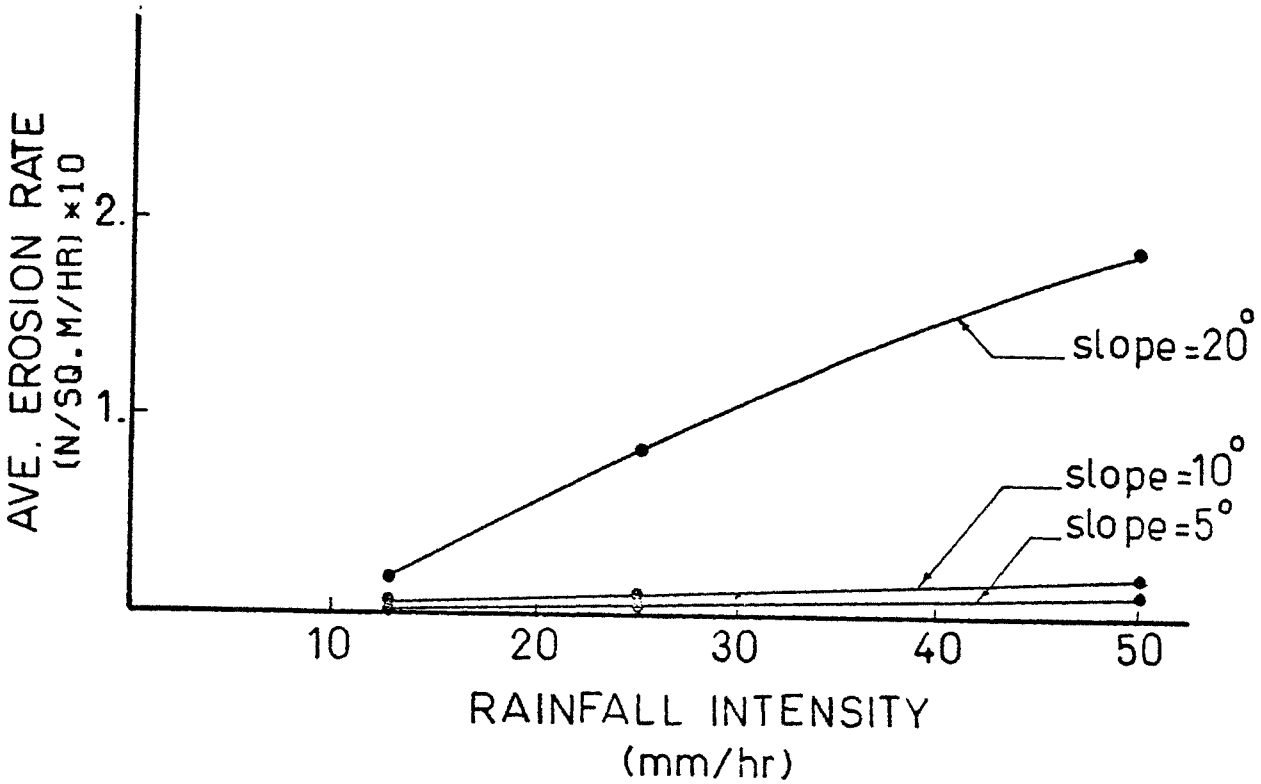


Figure 5.10 Relationship between Rainfall Intensity, Slope Gradient and Erosion Rate

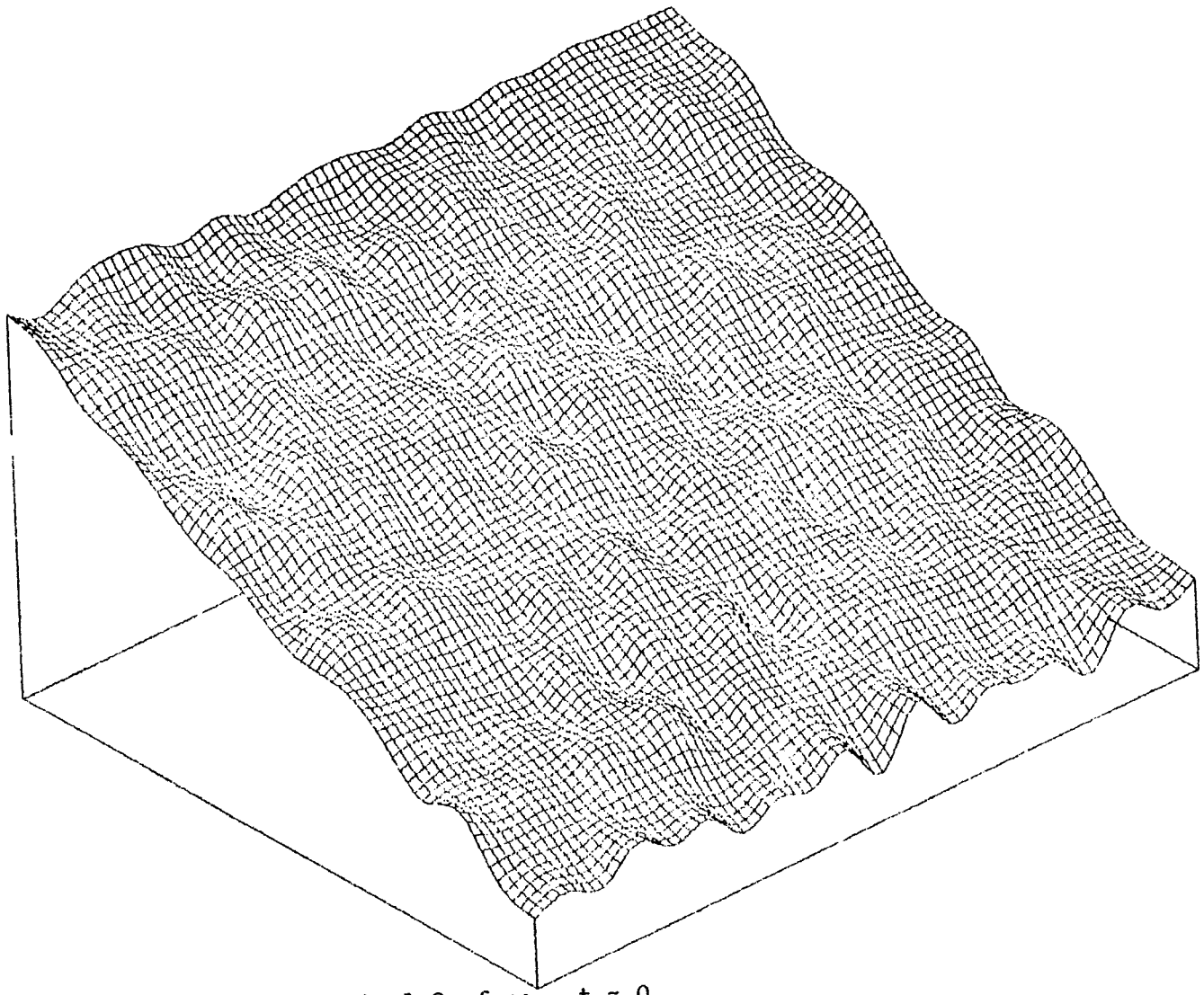


Figure 5.11 Original Surface, t = 0

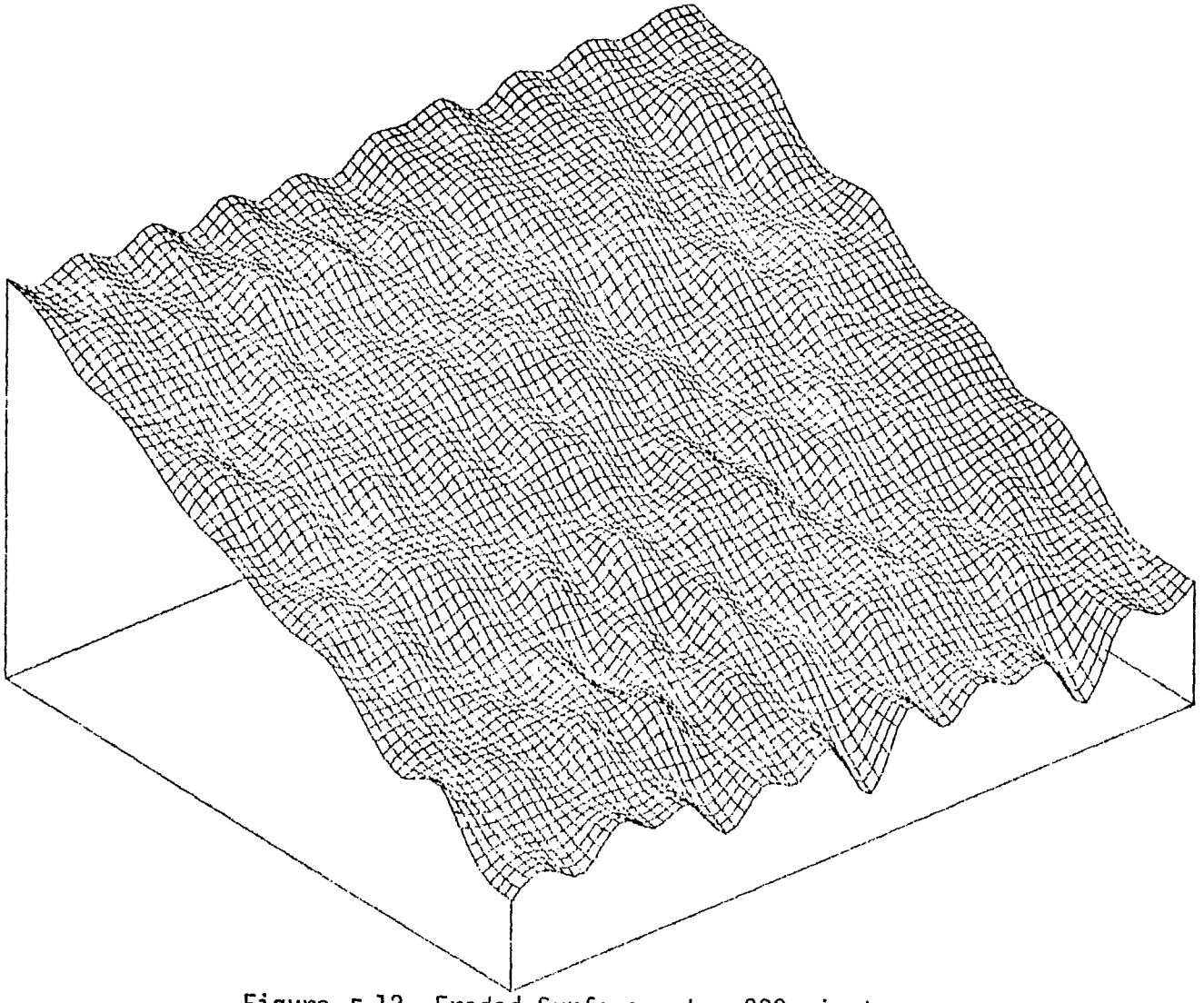


Figure 5.12 Eroded Surface; t = 200 minutes

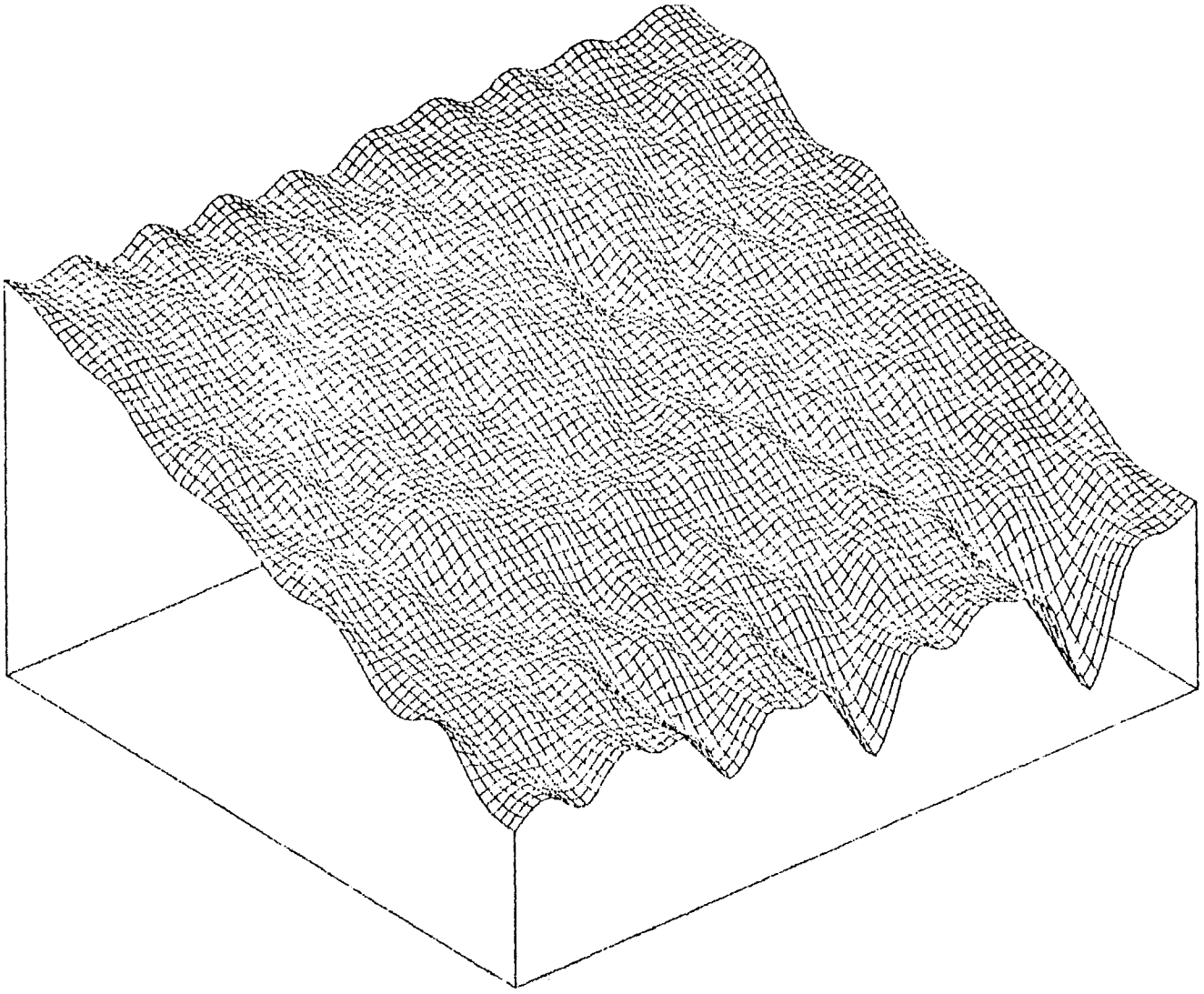


Figure 5.13 Eroded Surface, t = 400 minutes

5.3 Concluding Remarks

The limited number of tests that have been carried out indicate that the model calculates erosion rates that are of the right order of magnitude. The model performance is also in general agreement with available experience on the influence of the important physical conditions of slope gradient, slope length and rainfall intensity. It is realized that the tests are very approximate in nature and do not provide a verification of the model. An adequate test of the model would require a specially designed field experiment in which all of the model inputs and outputs will be measured. Then one will be in a better position to identify shortcomings in the model.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and Conclusions

The review of literature on soil erosion reveals the need to consider the effect of the random rill patterns which develop as a result of the surface roughness characteristics. A model has been developed to account for this effect in the simulation of the erosion process. The model computes the erosion and flow pattern and also the rill-interrill characteristics as they change with space and time.

The measured roughness of a surface is analyzed and used to generate random surfaces for the simulation process. Computations are carried out over a number of time intervals; the steady state condition is assumed for each interval. Changes in the surface geometry, due to erosion during an interval are used to revise the surface for the subsequent interval. The model includes simplified mechanicsms to simulate ponding, deposition, and failure of side slopes of rills.

A sensitivity analysis of the model was made to examine the effect of important parameters and mechanisms. The length of time intervals is important because of the cumulative effect of the surface-updating procedure. Therefore, shorter time intervals give better estimates of erosion rate. Manning's coefficient has a strong influence on the erosion rate; the erosion rate increases with the increasing values of Manning's coefficient, n. The transport capacities of flow in rills and over interrill areas also depends on the constants ASR and ASH. The value of ASR does not have

significant effect on the total erosion rate. However, an increase in ASR produces higher rill-interrill erosion ratio. The model is more sensitive to the value of ASH. An increase in ASH increases the erosion rate and, at the same time, decreases rill-interrill erosion ratio. The model is sensitive to the exponent p in Kalinske's bed load equation. A lower value of p results in a higher erosion rate and a higher rill-interrill erosion ratio.

The randomness in the surface elevation has a significant effect on reducing the erosion rate. Surfaces with greater random variations experience smaller erosion rates. Randomness in the rill pattern appears to have a smaller effect; the distribution of rill flow for the uniform rill pattern has more variations than that for the random rill pattern. However, the results are not considered conclusive because of the small sample size used in the analysis.

The model predictions were compared with some data from field experiments. The results are of the right order of magnitude, but it is not possible to make detailed comparisons because many parameters and data, including the original surface roughness, are not available.

The effects of the slope gradient, length of the slope, and rainfall intensity on the erosion rate were also studied. The results are in general agreement with experience.

6.2 Recommendations for Further Research

Because this is a first step in stochastic simulation of the erosion process, numerous problems both in formulation and in documentation have been encountered. Consequently, many simplifications

were made. The structure of the simulation model, however, has sufficient flexibility to allow refinements of the different sub-models and mechanisms.

Proper verification of the model requires field experiements in which the model inputs and ouputs are accurately determined. This will allow a more detailed evaluation of the model. Presently, there is great uncertainty about the appropriate values for Manning's coefficient, the constant a_s, and the exponent p for overland flow.

Possible improvements of the model include separation of the detachment and the transport capacity of the rill flow, and consideration of energy continuity at nodal points. The study of the random rill patterns should be pursued further.

It is important to note that the stochastic model considers only the random characteristics of the surface roughness. Other factors such as rainfall distribution, soil properties , and infiltration, are also random in nature, and contribute to the randomness of the overall behavior. Recently, Freeze (9) presented a simulation model that accounts for some of those factors in overland flow. A similar technique can be used to account for these factors in the erosion model.

APPENDIX A. DETACHMENT BY RAINFALL

A.1 INTRODUCTION

Field experiments, Mutchler and Young (26) Young and Weirsma (42), have shown that raindrop impact is a major factor in soil detachment and empirical relations between the amount of soil detached and rainfall energy and intensity have been proposed (3,8). Detailed studies of the energy and forces of raindrop impact were made by Mutchler (25), Palmer(28), and Laws(16). A recent study by Cruse and Larson(5) indicated that the amount of soil detached by a raindrop of given size and velocity is dependent on the shear strength of the soil. The limited experimental work described in this appendix is a preliminary investigation to study the factors that control detachment by raindrop. The techniques and methods developed by Palmer (28) and Laws (16) for producing raindrops were used in this investigation. The objective is to find an approximate and simple relation that can be used in the erosion model.

A.2 EXPERIMENTAL PROGRAM

The experimental program consists of measurement of the soil detached by raindrops from specially prepared soil samples. Two sizes of raindrops, 5.0mm and 3.7mm, falling through a distance of 2.4m. were used. A schematic diagram of the equipment used for raindrop tests is shown in Fig. A.1. At the top is the reservoir for the water supply. Raindrops are formed by passing the water through the graded tube. The dimensions of the graded tube are chosen for the required drop diameter according to the results of Palmer. Table A.1 gives the tube sizes used to form drops

1. Reservoir
2. Graded Tube
3. Lucite Shield
4. Container
5. Soil Sample
6. Brass Pedistal

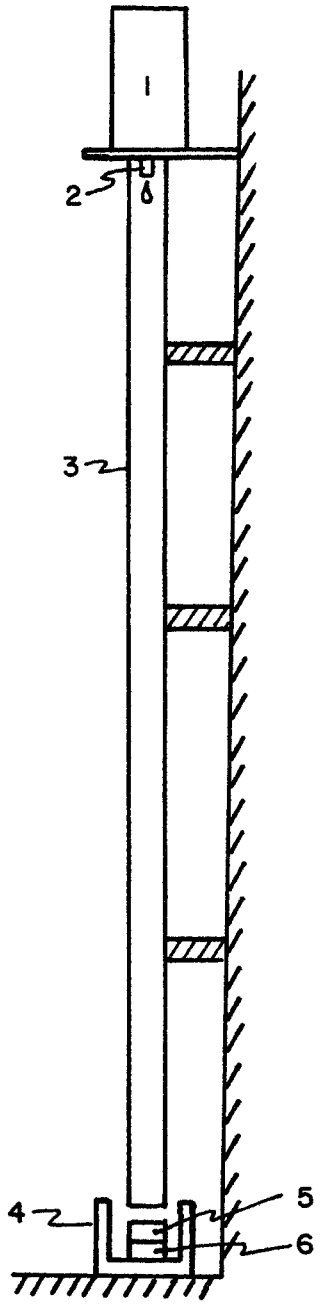
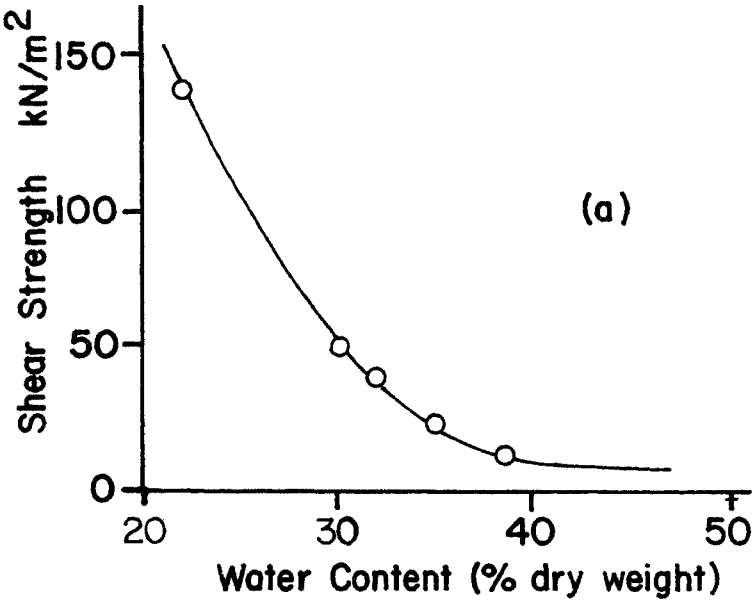


Figure A.1 : Apparatus for Raindrop Test
(not to scale)

TABLE A.1 MAKEUP OF GRADED TUBES

Tube Designation*	Gage Tubing	Inside Diameter (cm)
21 to 8	21	0.0495
(Drop diameter=5.0mm)	18	0.0838
	15	0.1371
	12	0.2159
	10	0.2692
	8	0.3430
21 to 18	21	0.0495
(Drop diameter=3.7mm)	18	0.0838

*Tube Designation refers to gage size of the tubing.



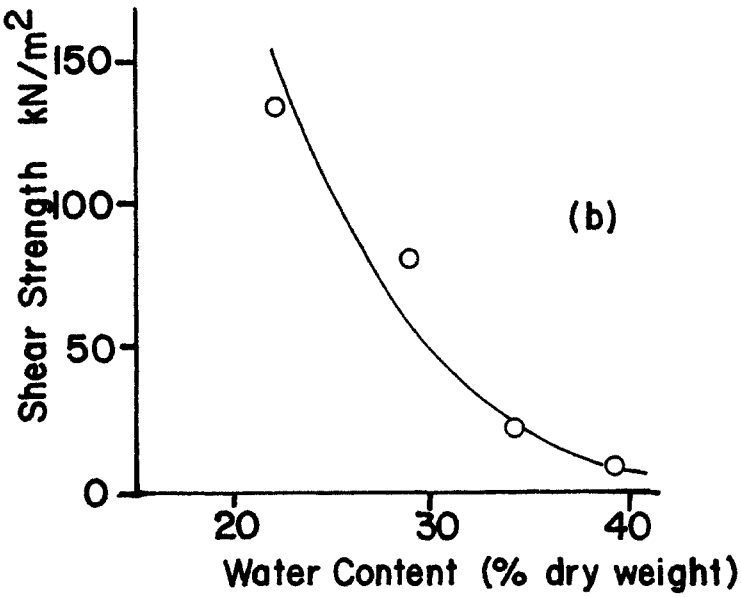
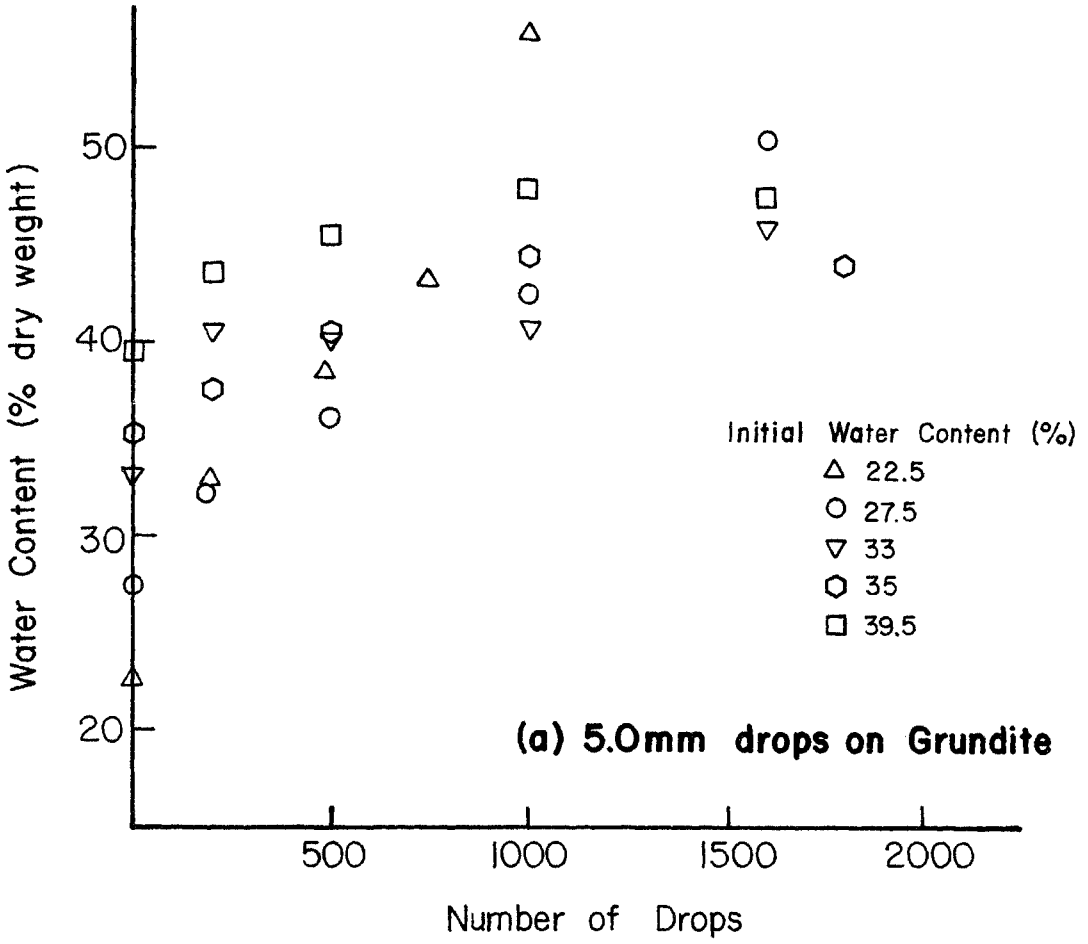


Figure A.2: Relation between Shear Strength and Water Content, (a) Kaolinite, (b) Grundite



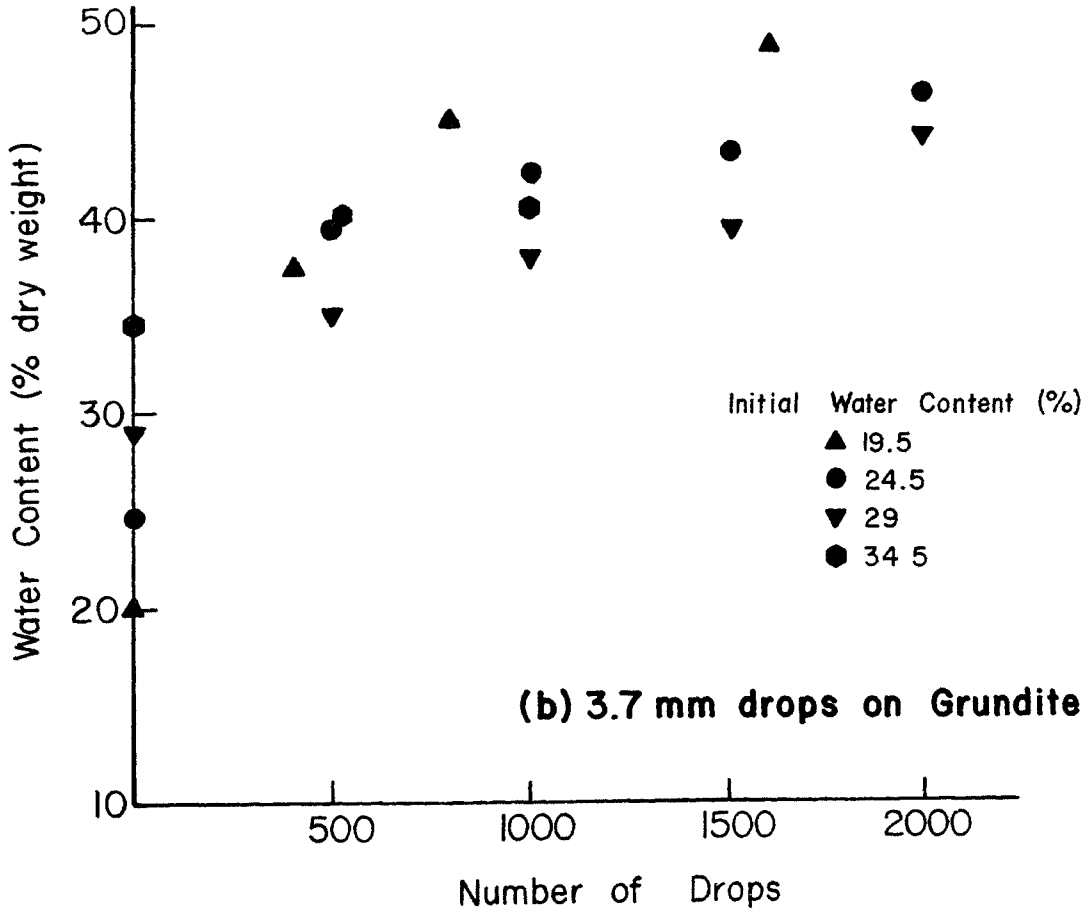
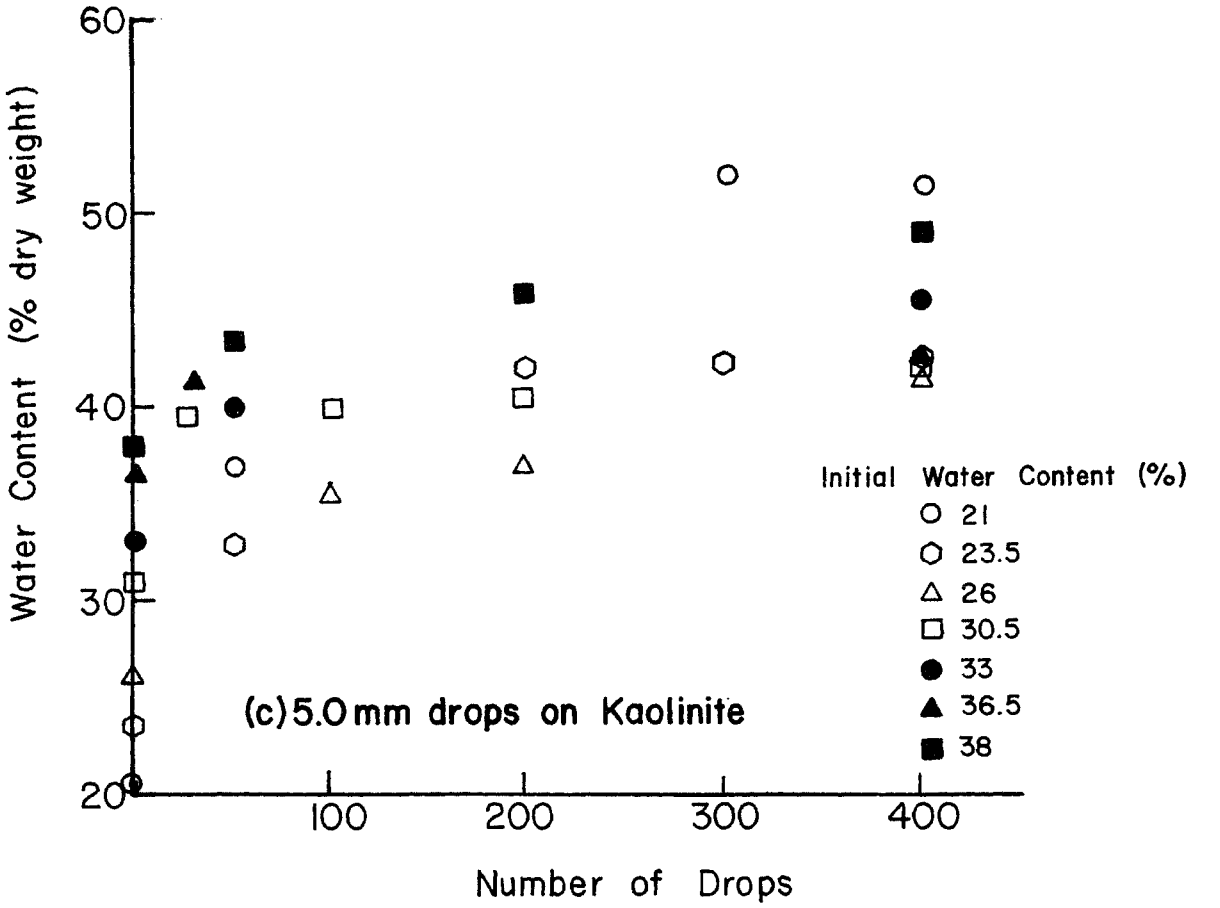


Figure A.3a,b: Change in Water Content with Raindrops



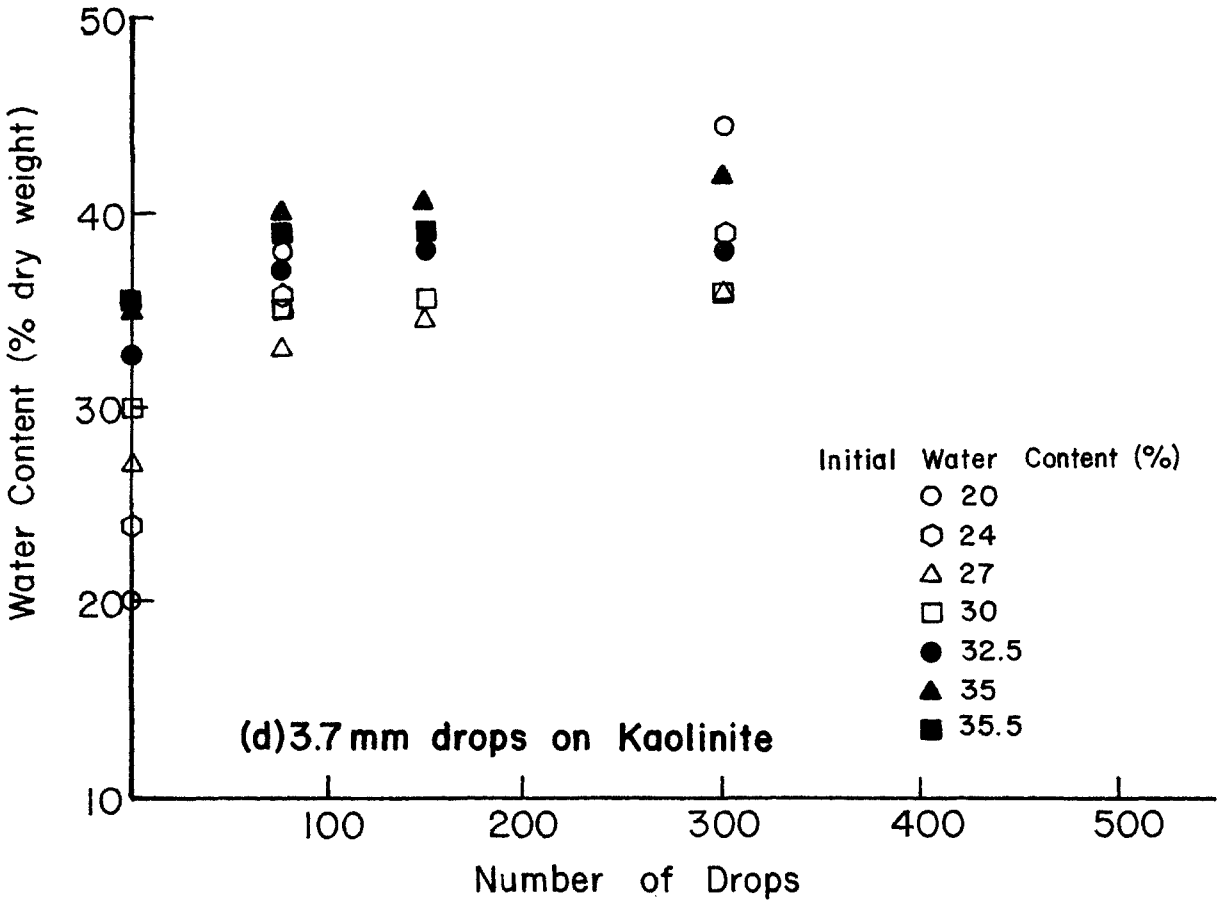


Figure A.3c,d: Change in Water Content with Raindrops

5.0 and 3.7mm in diameter. The flow rate through the formers are .078 and 030 N/min respectively. The lucite tube serves as a shield against air currents that may deflect the raindrops. The soil sample sits on a pedestal that is centered beneath the drop former, and the detached soil particles are retained in the container.

The soil samples were prepared from commercially made Kaolinite and Grundite whose index properties are summarized in Table A.2. The soil was compacted by the Harvard miniature compactor into a mold(39) with inside diameter of 3.33cm and a height of 7.15cm. The compaction was done in 5 layers with 25 tamps per layer and a force of 89 N. The water content was varied within a broad range and the undrained shear strength of the compacted soil was measured by the unconfined compression test. The relation between the shear strength, taken as equal to one-half the unconfined compression strength, and water content is shown in Fig. A.2 for the two materials.

The first series of raindrop tests measured the change in water content of the soil sample as it was subjected to increasing number of raindrops. In these tests the water content of the top layer, about 3mm. thick, of a soil sample was measured after a given number of raindrops had hit the top surface. The results are shown in Fig. A.3. The curves show the increase in water content with the number of raindrops for the two drop sizes and the two soils. In most cases, the water content increased rapidly at first and then approached a constant value. Some exceptions are noted; the samples with the low water contents in both groups show significant increases in water content throughout the test.

The second series of raindrop tests measured the amount of soil detached from the samples after it was subjected to a given number of raindrops. In these tests a sample was placed under the raindrop former and subjected to impact from raindrops. Soil particles that were detached

TABLE A.2

INDEX PROPERTIES OF KAOLINITE AND GRUNDITE

Soils	Liquid Limit %	Plastic Limit %	Initial Water Content %	Clay Fraction (<0.002 mm) %	Specific Gravity of Solid
Kaolinite	59	32	40	53	2.64
Grundite	54.4	26.1	45	53	2.78

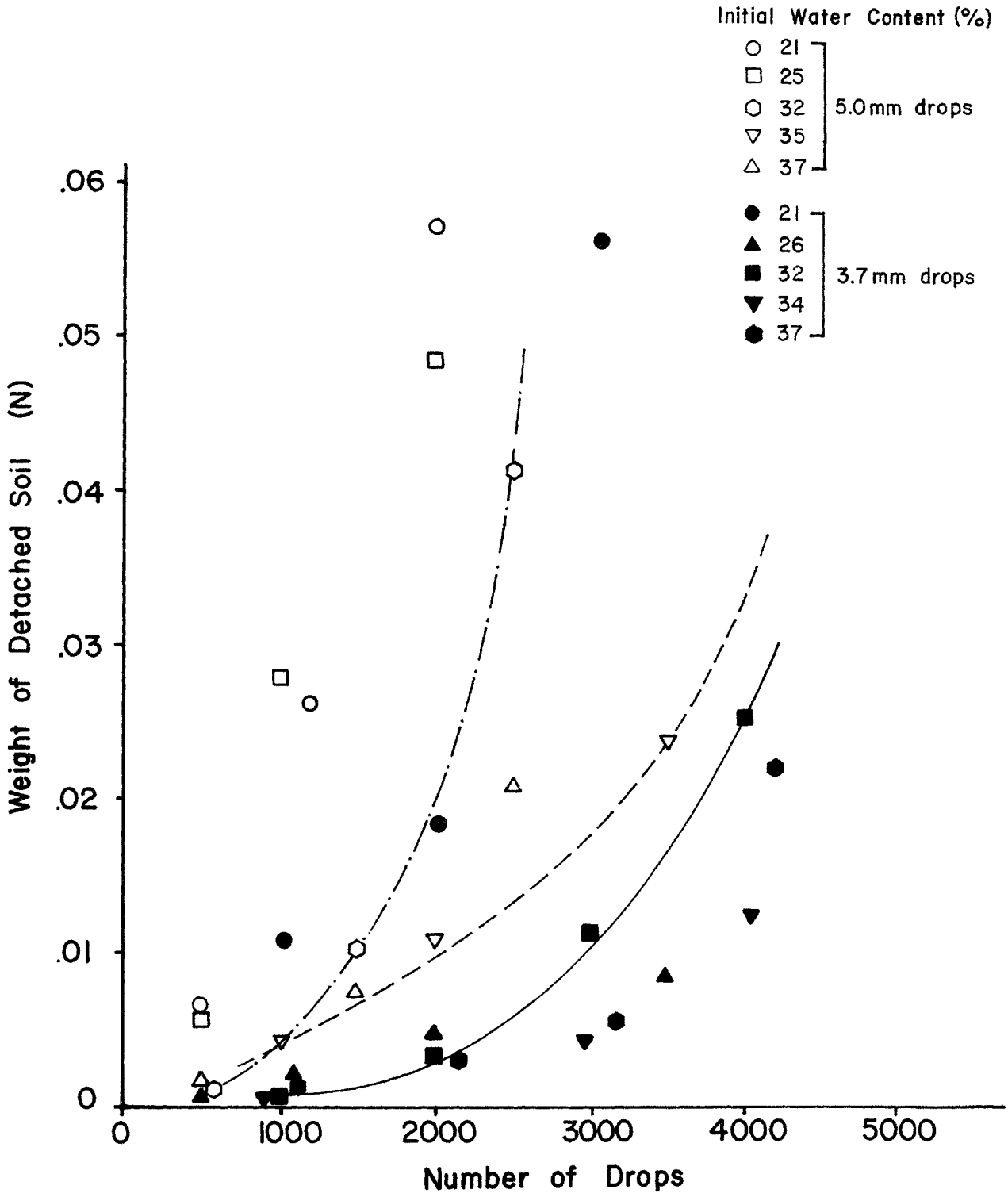


Figure A.4(a): Weight of Soil Detached and Number of Raindrops, Grundite

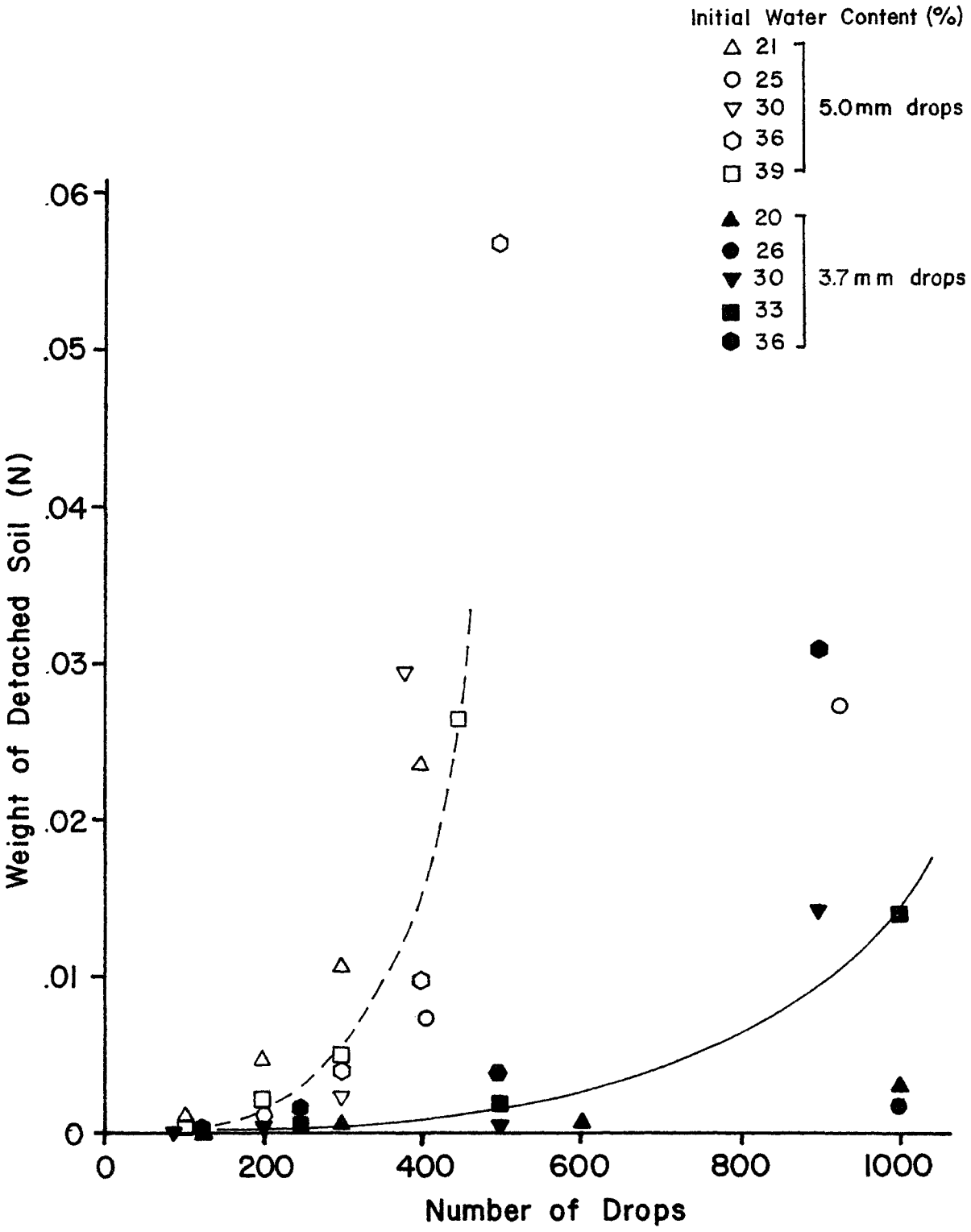


Figure A.4(b): Weight of Soil Detached and Number of Raindrops, Kaolinite

were collected in the container that enclosed the sample. After a certain number of drops had fallen on the sample, the detached soil in the container was collected and their dry weights were measured. The weight of soil detached as a function of the number of raindrops are plotted in Fig. A.4.

A.3 ANALYSIS OF RESULTS

The main objective of these experiments is to explore possible ways to model detachment of cohesive soil by raindrops. The data in Fig. A.4 indicate that the rate of soil detachment is at first slow and then increases rapidly. Lines are drawn through data points of selected tests to show the trend. The threshold number of raindrops N_0, beyond which detachment becomes very large depends on the soil, the water content, and the raindrop size. It should be noted that after about .05N of soil had been detached, the top 1cm of the soil samples was in a state of disintegration. At this point, the sample had absorbed enough water as indicated by the data in Fig. A.3, that its strength was very low and could offer little resistance to the raindrops.

Based on the above observations, a model that may be used as a first approximation of the detachment of cohesive soils is that, up to the threshold number of drops N_0, no soils is detached and the erosion is zero. After the number of drops exceeds N_0, the soil clod disintegrates and behaves as a cohesionless material. The laws of sediment transport for cohensionless soils may then be applied. For convenience, the number of drops N_0 should be expressed in terms of rainfall quantities. This can be done by computing the volume of water and dividing it by the area of the soil sample. For the 5mm diameter drop, 1000 drops corresponds to 6.54 cm. of rainfall.

APPENDIX B

COMPARISON OF COMPUTED AND MEASURED RILL EROSION

Meyer et al. (24) measured will erosion under simulated rainfall on artificial rills, prepared in a Russell silt loam field. The rills were 4.6 m long and had bed slope of 6% and side slopes of 25%. The present comparison is made for the case of 64 mm/hr rainfall intensity. The test was conducted for several values of base flow, as shown in Table A.1.

To use Equation (3.18), which is derived for rill erosion, several constants and parameters in the equation must be estimated. The silt loam was assumed to aggregate and form larger particles of diameter 0.2 mm. Since the test was performed on rill erosion, the value of the constant a_s was taken as 300. The exponent p was kept equal to 2.0. For a Manning coefficient of 0.025 and a runoff factor of 0.5, the computed erosion for different base flows is given in Table B.1.

TABLE B.1 COMPARISON BETWEEN MEASURED AND COMPUTED VALUES OF RILL EROSION

		MEASURED		COMPUTED FROM EQUATION (3.18)	
Base Flow Q_1, N/hr	End Flow Q_2, N/hr	Soil Loss* N	Erosion Rate N/hr/m	E_R $m^3/sec/m$	Erosion Rate N/hr/m
0	1140	15.1	03.2	0.031×10^{-6}	01.5
7000	7300	49.8	10.8	0.53×10^{-6}	25
7000	7100	48.9	10.7	0.53×10^{-6}	25
14000	14360	184.5	40.1	0.53×10^{-6}	45
14000	12000	93.5	20.3	0.53×10^{-6}	45
20000	20500	357.2	77.6	1.31×10^{-6}	61
20000	20070	132.0	28.7	1.31×10^{-6}	61
28000	29600	374.0	81.3	1.75×10^{-6}	81
28000	28850	418.5	91.0	1.75×10^{-6}	81

* Values indicated are the net soil loss from rill erosion only. It is computed by deducting the interrill erosion, as estimated by Meyer et al. (22), from the total measured soil loss.

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APPENDIX D

LISTING AND SAMPLE OUTPUT OF THE COMPUTER PROGRAM

```
C                                                                       A00010
C                                                                       A00020
C                                                                       A00030
C                        **********************                         A00040
C                        * A STOCHASTIC MODEL *                         A00050
C                        *         FOR        *                         A00060
C                        *     SOIL EROSION   *                         A00070
C                        *         BY         *                         A00080
C                        *  MOSTAFA MOSSAAD   *                         A00090
C                        *     APRIL 1981     *                         A00100
C                        **********************                         A00110
C                                                                       A00120
C                                                                       A00130
C                                                                       A00140
C                                                                       A00150
C     ***************************************************************   A00160
C     DEFINITION OF PRINCIPAL VARIABLES :                               A00170
C     **********************************                                A00180
C     NP= # OF POINTS ON EACH PROFILE                                   A00190
C     NPF= # OF PROFILES                                                A00200
C     CUT= CUTOFF LENGTH (IF USED AS A LOW-PASS FILTER).                A00210
C     TLEN= TOTAL LENGTH OF MICRORELIEF PROFILE.                        A00226
C     DX= DISTANCE BETWEEN ROUGHNESS DATA MEASUREMENTS                  A00230
C                                                                       A00240
C     DMLM= REPRESENTATIVE SOIL PARTICLE DIAMETER, MILLIMETER           A00250
C     UWT= UNIT WEIGHT OF SOIL ,N/CUBIC METER                           A00260
C     RO= DENSITY OF WATER, KG/C. METER                                 A00270
C     G= GRAVITY ACCEL. M/SQ. SEC                                       A00280
C     SG= SPECIFIC GRAVITY OF SOIL                                      A00290
C                                                                       A00300
C     RN= MANNING'S COEFFICIENT                                         A00310
C     P= EXPONENT IN KALINSKE'S EQUATION                                A00320
C     ASR= CONSTANT IN RILL EROSION EQUATION                            A00330
C     ASH= CONSTANT IN INTERRILL EROSION EQUTION                        A00340
C                                                                       A00350
C     NX= # OF MESH POINTS IN X-DIRECTION                               A00360
C     NY= # OF MESH POINTS IN Y-DIRECTION                               A00370
C     SLOPE= AVERAGE SLOPE OF SURFACE, DEGREES                          A00380
C     RNL= RAIFALL INTENSITY, MLMTR/HR                                  A00390
C     RNF= RUNOFF COEFFICIENT                                           A00400
C     ANRATE= ANNUAL RATE OF RAIN                                       A00410
C     TI= DURATION OF TIME INTERVAL, MINUTES                            A00420
C     NTI= # OF TIME INTERVALS                                          A00430
C     NRS= # OF RANDOM SURFACES (I.E. SAMPLE SIZE)                      A00440
C                                                                       A00450
C     AMP= AMPLITUDE OF BASIC WAVE                                      A00460
C     WL= WAVELENGTH OF  " " " " " " " " " " " " " " "                  A00470
C     SL= LENGTH OF SHORT SIDE OF BASIC RECTANGULAR MESH ELEMENT, METER  A00480
C     SH= HORIZONTAL PROJECTION OF SL                                   A00490
C                                                                       A00500
C     SDT(I)= TOTAL VOLUME OF SEDIMENT WHICH PASSED BY POINT I          A00510
C     DURING A TIME INTERVAL, CUBIC METERS                              A00520
C     TRE(I)= VOLUME OF RILL EROSION PART OF SEDIMENT WHICH PASSED      A00530
C     BY POINT I DURING A TIME INTERVAL, C. METERS                      A00540
C     TIRE(I)= VOLUME OF INTERRILL EROSION PART OF SEDIMENT WHICH       A00550
C     PASSED BY POINT I DURING A TIME INTERVAL, C. METERS               A00560
C     TTBTM= WEIGHT OF TOTAL SEDIMENT ACCUMULATED AT THE BOTTOM DURING  A00570
C     A TIME INTERVAL ,NEWTONS                                          A00580
C     THBTM= WT. OF INTER-RILL EROSION  " " " " " " " " " " " "         A00590
C     TRBTM= WT. OF RILL-EROSION  " " " " " " " " " " " " " "           A00600
C     RATIO= RILL/INTERRILL EROSION DURING A TIME INTERVAL              A00610
C     RATE= EROSION RATE IN N/SQ. M/HR  " " " " " " " " "               A00620
C     FTSDT(NS)= TOTAL SDMT. FROM RANDOM SURFACE NO. NS ,NEWTONS        A00630
C     FRSDT(NS)= RILL EROSION  " " " " " " " " " " " "                  A00640
C     FHSDT(NS)= INTER RILL EROSION  " " " " " " " " "                  A00650
C     FRATIO(NS)= TOTAL RILL/INTERRILL EROSION RATIO " "                A00660
C     FRATE(NS)= TOTAL EROSION RATE  " " " " " " " " "                  A00670
C     ***************************************************************   A00680
C                                                                       A00690
C     ***************************************************************   A00700
C     DATA CARDS ARE PUT IN THE FOLLOWING ORDER :                       A00710
C     1) NP,NPF,CUT,TLEN,DX   (SEE FORMAT STATMENT # 1)                 A00720
C     2) ROUGHNESS DATA CARDS (SEE FORMAT STATMENT # 2)                 A00730
C     3) DMLM,UWT,RO,G,SG     (SEE FORMAT STATMENT # 3)                 A00740
C     4) RN,P,ASR,ASH         (SEE FORMAT STATMENT # 4)                 A00750
C     5) NX,NY,SLOPE,RNL,RNF,ANRATE  (SEE FORMAT STATMENT # 5)          A00760
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```
C     6) TI,NTI,NRS            (SEE FORMAT STATMENT # 6)                    A00770
C     7) SLIMIT,SSTART         (SEE FORMAT STATMENT # 7)                    A00780
C     8) NRUN (I5), SEE NOTE # 2                                            A00790
C     9) NRUN VALUES OF PARAMETER BEING STUDIED, SEE NOTE # 2               A00800
C     ******************************************************************    A00810
C                                                                           A00820
C     NOTE # 1                                                              A00830
C     *******                                                               A00840
C     THIS PROGRAM USES TWO SUBROUTINES CALLED FFTR AND FFTP FROM           A00850
C     THE "IMSL" LIBRARY:                                                   A00860
C     FFTR : COMPUTES FOURIER TRANSFORM, AND                                A00870
C     FFTP : COMPUTES INVERSE FOURIER TRANFORM.                             A00880
C     MAKE SURE THEY STILL EXIST IN THE COMPUTER LIBRARY UNDER              A00890
C     THE SAME NAME                                                         A00900
C     ******************************************************************    A00910
C                                                                           A00920
      DIMENSION VARPLT(10)                                                  A00930
      DIMENSION  XP(200),YP(200),RSD(200)                                   A00940
      DIMENSION YYP(1000)                                                   A00950
      DIMENSION TBTM(100),RBTM(100),HBTM(100)                               A00960
      DIMENSION  FTSDT(100),FRSDT(100),FHSDT(100),FRATIO(100),FRATE(100)    A00970
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                    A00980
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                     A00990
      COMMON/QFLOW/QT(2000),QL(2000),QR(2000)                               A01000
      COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000)                           A01010
      COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)                            A01020
      COMMON/HMMPP/HMMP(500),XHMP(500),YHMP(500)                            A01030
      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),      A01040
     #  HMP6(500)                                                           A01050
      COMMON /SAME/TLEN,CUT                                                 A01060
      COMMON /PROP/GAMA,RO,G,SG,RN                                          A01070
      COMMON NT                                                             A01080
C                                                                           A01090
C     ******************************************************************    A01100
C     READ SURFACE ROUGHNESS DATA                                           A01110
C     ******************************************************************    A01120
C                                                                           A01130
      READ(5,1) NP,NPF,CUT,TLEN,DX                                          A01140
      NTOTAL=NP*NPF                                                         A01150
      READ(5,2)(YYP(I),I=1,NTOTAL)                                          A01160
C                                                                           A01170
C     ******************************************************************    A01180
C     READ PHYSICAL PARAMETERS                                              A01190
C     ******************************************************************    A01200
C                                                                           A01210
      READ(5,3) DMLM,UWT,RO,G,SG                                            A01220
      READ(5,4)RN,P,ASR,ASH                                                 A01230
C                                                                           A01240
C     ******************************************************************    A01250
C     READ STORM AND SLOPE DATA                                             A01260
C     ******************************************************************    A01270
C                                                                           A01280
      READ(5,5) NX,NY,SLOPE,RNL,RNF,ANRATE                                  A01290
      READ(5,6) TI,NTI,NRS                                                  A01300
      READ(5,7) SLIMIT,SSTART                                               A01310
      D=DMLM/1000.                                                          A01320
      TTIME=TI*NTI/60.                                                      A01330
C                                                                           A01340
C     THE FOLLOWING FOUR CARDS ARE TO BE USED ONLY WHEN                     A01350
C     COMPUTING RESULTS FOR (NRUN) VALUES OF ANY PARAMETER. FOR             A01360
C     EXAMPLE, RN. IN THE CASE BELOW                                        A01370
C           READ(5,2000)KRUN                                                A01380
C     READ(5,3000)(VARPLT(I),I=1,KRUN)                                      A01390
C     DO 1000 NRUN=1,KRUN                                                   A01400
C        RN=VARPLT(NRUN)                                                    A01410
C     WRITE(25) NRUN,VARPLT(NRUN)                                           A01420
 2000 FORMAT(I5)                                                            A01430
 3000 FORMAT(10F8.3)                                                        A01440
C                                                                           A01450
      SLPR=TAN(SLOPE*22./7./180.)*100                                       A01460
      RAINYR=RNL*TTIME/ANRATE/10.                                           A01470
      WRITE(6,30)                                                           A01480
      WRITE(6,209)                                                          A01490
      WRITE(6,203)                                                          A01500
      WRITE(6,230)                                                          A01510
      WRITE(6,203)                                                          A01520
```

```
      WRITE(6,209)                                                      A01530
      WRITE(6,310)                                                      A01540
      WRITE(6,315)                                                      A01550
      WRITE(6,320) NPF,NP,DX                                            A01560
      WRITE(6,330)                                                      A01570
      WRITE(6,315)                                                      A01580
      WRITE(6,340) DMLM,UWT,SG                                          A01590
      WRITE(6,350) P,ASR,ASH,RN                                         A01600
      WRITE(6,360)                                                      A01610
      WRITE(6,315)                                                      A01620
      WRITE(6,370)NX,NY,SLOPE,SLPR,RNL,RNF                              A01630
      WRITE(6,375) ANRATE,RAINYR                                        A01640
      WRITE(6,380) TI,TTIME,NRS                                         A01650
      WRITE(6,390) SLIMIT,SSTART                                        A01660
      WRITE(6,60)                                                       A01670
      XP(1)=0.0                                                         A01680
      DO 14 I=2,NP                                                      A01690
      XP(I)=XP(I-1)+DX                                                  A01700
   14  CONTINUE                                                         A01710
      IF(NRUN.GT.1) GO TO 4000                                          A01720
      WRITE(6,50)                                                       A01730
      WRITE(6,209)                                                      A01740
      WRITE(6,203)                                                      A01750
      WRITE(6,400)                                                      A01760
      WRITE(6,203)                                                      A01770
      WRITE(6,209)                                                      A01780
C                                                                       A01790
C     ****************************************************************  A01800
C ... DETERMINE THE CHARACTERISTICS OF THE BASIC WAVE                   A01810
C     ****************************************************************  A01820
C                                                                       A01830
      CALL       CWAVE(XP,YP,YYP,NP,NPF,CUT,TLEN,AMP,WL,RSD,            A01840
     #  RMEAN,STDEV)                                                    A01850
      WRITE(6,300) AMP,WL                                               A01860
C                                                                       A01870
      WRITE(6,305) RMEAN,STDEV                                          A01880
C ... CONVERT TO METERS                                                 A01890
C                                                                       A01900
      AMP=AMP/1000.                                                     A01910
      WL=WL/100.                                                        A01920
      STDEV=STDEV/1000.                                                 A01930
      RMEAN=RMEAN/1000.                                                 A01940
C                                                                       A01950
C     ****************************************************************  A01960
C ... CONSTRUCT THE HEXAGONAL MESH                                      A01970
C     ****************************************************************  A01980
C                                                                       A01990
      SL=WL/(2.*(3.**0.5))                                              A02000
      SLP=SLOPE*22./7./180.                                             A02010
      SH=SL*COS(SLP)                                                    A02020
 4000 CONTINUE                                                          A02030
      DO 3007 I=1,NMAX                                                  A02040
      X(I)=0.                                                           A02050
      Y(I)=0.                                                           A02060
      CODE(I)=0                                                         A02070
      NAJ(I)=0                                                          A02080
      KPND(I)=0                                                         A02090
 3007  CONTINUE                                                         A02100
      CALL HXMESH                                                       A02110
      TAREA=Y(NY)*X(NMAX)                                               A02120
      FSHAPE=X(NMAX)/Y(NY)                                              A02130
      PL=Y(NY)                                                          A02140
      PW=X(NMAX)                                                        A02150
      WRITE(6,40)PL,PW                                                  A02160
      WRITE(6,30) TAREA,FSHAPE                                          A02170
      WRITE(6,60)                                                       A02180
      GAMA=RO*G/9.81                                                    A02190
C                                                                       A02200
C     ****************************************************************  A02210
C ... COMPUTE PARAMETERS OF EROSION EQUATIONS                           A02220
C     ****************************************************************  A02230
C                                                                       A02240
      CALL       PARAM(D,P,ASR,ASH,RCH,HCH,EX)                          A02250
C                                                                       A02260
C ... START DO LOOP 200 FOR DIFFERENT RANDOM SURFACES                   A02270
```

```
C
      DO 200 NS=1,NRS
      DO 201  I=1,NMAX
      ELV(I)=0.0
      DH(I)=0.0
  201 HHMP(I)=0.0
      DO 202   I=1,NRS
      FTSDT(I)=0.0
      FRSDT(I)=0.0
      FHSDT(I)=0.0
      FRATIO(I)=0.0
  202 FRATE(I)=0.0
C
C ... ASSIGN ORIGINAL ELEVATIONS TO ALL MESH POINTS
C
      CALL        ELEVTN(SLOPE,AMP,RMEAN,STDEV,NS)
C
C ... ASSIGN CALL NUMBERS,COORDINATES ,AND ELEVATIONS TO ALL HUMPS
C
      CALL        HUMP(RMEAN,STDEV,SLOPE,AMP,NHUMP)
      WRITE(6,204)
      WRITE(6,203)
      WRITE(6,205)   NS
      WRITE(6,203)
      WRITE(6,209)
      WRITE(6,206)
      WRITE(6,207)
      WRITE(6,208)
C
C ... START DO LOOP 100 FOR THE SEQUENCE OF TIME INTERVALS FOR THE
C     RANDOM SURFACE UNDER CONSIDERATION
C
      DO 100 NT=1,NTI
      DO 101  I=1,NMAX
      SDT(I)=0.0
      TRE(I)=0.0
      TIRE(I)=0.0
      QL(I)=0.0
      QR(I)=0.0
      QT(I)=0.0
      IF(Y(I).EQ.0.0.AND.KPND(I+1).EQ.0)  DH(I)=DH(I+1)
      ELV(I)=ELV(I)-DH(I)
      DH(I)=0.0
  101 CONTINUE
      CALL        SFAILR(SLIMIT,SSTART)
      CALL        POND
      CALL        ACJNT
  888 FORMAT(3(I5,F15.5,I5))
C
C ... STORE INITIAL ELEVATIONS OF ALL POINTS ON FILE # 35
C
      IF(NT.GT.1)  GO TO 635
      REWIND 35
      CALL        STORE(NNOD,NHUMP)
  635 CONTINUE
C
C     ********************************************************************
C ... COMPUTE STEADY STATE FLOW AT MESH POINTS DURING A TIME INTERVAL
C     ********************************************************************
C
      CALL        FLOW(RNL,RNF)
      NVOID=0
      DO 70 LL=1,NY
      KK=NY+(1-LL)
      DO 70  I=KK,NMAX,NY
      IF(Y(I).EQ.0.0)  GO TO 75
      IF(CODE(I)-1)  75,80,85
C
C     ********************************************************************
C ... COMPUTE EROSION FOR RILL SEGMENTS WITH UPSTREAM POINT HAVING
C     CODE=1.
C     ********************************************************************
C
   80 CALL  ERSN1(I,QT(I-1),HCH,RCH,EX,TI)
      GO TO 70
C
```

```
C     ****************************************************************      A03040
C ... COMPUTE EROSION FOR RILL SEGMENTS WITH UPSTREAM POINT HAVING          A03050
C     CODE=2.                                                               A03060
C     ****************************************************************      A03070
C                                                                           A03080
  85  CALL ERSN2(I,QL(I),QR(I),HCH,RCH,EX,TI)                              A03090
  75  IF(CODE(I).EQ.0.0) NVOID=NVOID+1                                      A03100
  70  CONTINUE                                                              A03110
 777  FORMAT(3(I5,2F15.5))                                                  A03120
      DO 105  I=1,NHUMP                                                     A03130
 999  FORMAT(I5,7F15.5)                                                     A03140
 105  HHMP(I)=(HMP1(I)+HMP2(I)+HMP3(I)+HMP4(I)+HMP5(I)+HMP6(I))/6.         A03150
      TTBTM=0.0                                                             A03160
      TRBTM=0.0                                                             A03170
      THBTM=0.0                                                             A03180
      DO 110  K=1,NX                                                        A03190
      J=1+(K-1)*  NY                                                        A03200
      TBTM(K)=SDT(J)*UWT                                                    A03210
      TTBTM=TTBTM+TBTM(K)                                                   A03220
      RBTM(K)=TRE(J)*UWT                                                    A03230
      TRBTM=TRBTM+RBTM(K)                                                   A03240
      HBTM(K)=TIRE(J)*UWT                                                   A03250
      THBTM=THBTM+HBTM(K)                                                   A03260
 110  CONTINUE                                                              A03270
      RATIO=TRBTM/THBTM                                                     A03280
      RATE=TTBTM*60/TAREA/TI                                                A03290
C                                                                           A03300
C ... STORE EROSION RATE RESULTS ON FILE # 25                               A03310
C                                                                           A03320
      XPLT=TI*NT                                                            A03330
      YPLT=RATE                                                             A03340
      ZPLT=RATIO                                                            A03350
      WRITE(25)  XPLT,YPLT,ZPLT                                             A03360
      FTSDT(NS)=FTSDT(NS)+TTBTM                                             A03370
      FRSDT(NS)=FRSDT(NS)+TRBTM                                             A03380
      FHSDT(NS)=FHSDT(NS)+THBTM                                             A03390
      FRATIO(NS)=             FRSDT(NS)/FHSDT(NS)                           A03400
      FRATE(NS)=FTSDT(NS)*60.0/TAREA/TI/NT                                  A03410
      WRITE(6,210) NT,TTBTM,RATIO,RATE,FTSDT(NS),FRATIO(NS),FRATE(NS)       A03420
 260   FORMAT(130('*'),/,130('*'))                                          A03430
 100  CONTINUE                                                              A03440
      NNOD=NMAX-NVOID                                                       A03450
C                                                                           A03460
C ... STORE FINAL   ELEVATIONS OF ALL POINTS ON FILE # 35                   A03470
C                                                                           A03480
      CALL        STORE(NNOD,NHUMP)                                         A03490
      END FILE 35                                                           A03500
C                                                                           A03510
C ... CHECK DATA STORED ON FILE # 35                                        A03520
C     REWIND 35                                                             A03530
C625  READ(35,END=600)NY,NNOD,NHUMP                                         A03540
C     WRITE(6,630)  NY,NNOD,NHUMP                                           A03550
C630  FORMAT(3I10)                                                         A03560
C     READ(35)XMAX,YMAX                                                     A03570
C     WRITE(6,612)XMAX,YMAX                                                 A03580
C612  FORMAT(2F20.5)                                                       A03590
C605  READ(35,END=600)  XXX,YYY,ZZZ                                        A03600
C     WRITE(6,610)  XXX,YYY,ZZZ                                             A03610
C     IF(XXX.GT.88887.)  GO TO 625                                          A03620
C     GO TO 605                                                             A03630
C600  CONTINUE                                                            A03640
C610  FORMAT(3F20.5)                                                       A03650
C                                                                           A03660
 200  CONTINUE                                                              A03670
      WRITE(6,220)                                                          A03680
      WRITE(6,211)                                                          A03690
      WRITE(6,212)                                                          A03700
      WRITE(6,215)(I,FTSDT(I),FRSDT(I),FHSDT(I),FRATIO(I),FRATE(I),I=1,     A03710
     #  NRS)                                                                A03720
      XPLT=99999.                                                           A03730
      WRITE(25)  XPLT,YPLT,ZPLT                                             A03740
 1000 CONTINUE                                                              A03750
      END FILE 25                                                           A03760
C                                                                           A03770
C ... CHECK DATA STORED ON FILE # 25                                        A03780
C     REWIND 25                                                             A03790
C     READ(25)  NRUN,VARPLT(NRUN)                                           A03800
```

```
C      WRITE(6,611) NRUN,VARPLT(NRUN)                                    A03810
C611   FORMAT(I10,F10.5)                                                 A03820
C333   READ(25,END=334)XX,YY                                             A03830
C      WRITE(6,335) XX,YY                                                A03840
C335   FORMAT(2F20.5)                                                    A03850
C      GO TO 333                                                         A03860
C 334   CONTINUE                                                         A03870
C                                                                        A03880
  1    FORMAT(2I4,3F8.2)                                                 A03890
  2    FORMAT(10F6.2)                                                    A03900
  3    FORMAT(5F10.4)                                                    A03910
  4    FORMAT(4F10.4)                                                    A03920
  5    FORMAT(2I5,4F10.3)                                                A03930
  6    FORMAT(F10.3,2I5)                                                 A03940
  7    FORMAT(2F10.4)                                                    A03950
  30   FORMAT(///,10X,'TEST AREA =',F10.3,' SQ. METERS',//,10X,          A03960
     #   'SHAPE FACTOR =',F10.3)                                         A03970
  40    FORMAT(//,10X,'PLOT LENGTH=',F10.3,'    METERS',//,10X,          A03980
     #   'PLOT WIDTH =',F10.3,'    METERS')                              A03990
  50   FORMAT(1H1,5X,110('*'),///)                                       A04000
  60    FORMAT(//,5X,110('*'))                                           A04010
 203   FORMAT(T23,'*',T54,'*',/,T23,'*',T54,'*')                         A04020
  204  FORMAT(1H1,///,23X,30('*'))                                       A04030
  205  FORMAT(T23,'*',T29,'RANDOM SURFACE NO. ',I3,T54,'*')              A04040
 206   FORMAT(///,T11,'RESULTS OF EACH INTERVAL',T51,'CUMULATIVE RESULTS' A04050
     #   ,/,T11,24('-'),T51,18('-'))                                     A04060
 207   FORMAT(/,3X,'INTRVL #',T13,'TTL SDMT',T23,'R/I RATIO',T34,        A04070
     # 'ERSN RATE',T47,'TTL SDMT',T57,'R/I RATIO',T69,'ERSN RATE')       A04080
 208   FORMAT(T15,'( N)',T33,'( N/SM/HR)',T49,'( N)',T68,'( N/SM/HR)')   A04090
  209  FORMAT(23X,30('*'))                                               A04100
  210  FORMAT(/,2X,I5,2X,3F10.2,'    *',3F10.2)                          A04110
  211  FORMAT(/////,T4,'NRS',T9 ,'TTL SDMT', T22,'R. ERSN.',T30,         A04120
     # 'I. ERSN.',T40,'R/I RATIO',T50,'ERSN. RATE')                      A04130
 212   FORMAT(T9,'(N)',T23,'(N)',T33,'(N)',T50,'(N/SM/HR)',//)           A04140
 215   FORMAT(I5,5F10.3,/)                                               A04150
  220  FORMAT(1H1,/////,15X,'FINAL RESULTS FOR ALL RANDOM SURFACES',/,   A04160
     #   15X,36('*'))                                                   A04170
 305   FORMAT(/,10X,'MEAN OF NORMAL DIST.          =',F8.3,'  MLMTR',//,  A04180
     #   10X,'STAND. DEVIATION OF NORMAL DIST.=',F8.3,'  MLMTR')        A04190
 300   FORMAT(///,10X,'AMPLITUDE OF REPRESENTATIVE WAVE=',F8.3,2X,'MLMR', A04200
     #   //,10X,'LENGTH OF REPRESENTATIVE WAVE   =',F8.3,2X,'CM')      A04210
  230  FORMAT(T23,'*',T29,'  I N P U T  D A T A  ',T54,'*')              A04220
 310   FORMAT(///,10X,'GROUP # 1 :',10X,'SURFACE ROUGHNESS DATA')        A04230
 315   FORMAT(10X,11('*'),10X,22('*'),/,10X,11('*'))                     A04240
 320   FORMAT(//,15X,'NO. OF ELEVATION TRACES =',I5,//,15X,              A04250
     #   'NO. OF POINTS PER TRACE =',I5,                                 A04260
     #//,15X,'SPACING                =',F5.2,3X,'CM')                   A04270
 330   FORMAT(///,10X,'GROUP # 2 :',10X,'  PROBLEM  PARAMETERS  ')       A04280
 340   FORMAT(//,15X,'SOIL PARTICLE DIAMETER    =',F5.3,3X,'MLMTR',      A04290
     #        //,15X,'SOIL UNIT WEIGHT          =',F6.0,3X,' N/C. METER', A04300
     #        //,15X,'SOIL SPECIFIC WEIGHT      =',F5.2)                 A04310
 350   FORMAT(//,15X,'EXPONENT OF KALINSKE EQN. =',F5.2,                 A04320
     #        //,15X,'EQN. CONSTANT FOR RILLS   =',F5.1,                 A04330
     #        //,15X,'EQN. CONSTANT FOR HUMPS   =',F5.1,                 A04340
     #        //,15X,'MANNING CONSTANT          =',F5.3)                 A04350
 360   FORMAT(///,10X,'GROUP # 3 :',10X,' STORM AND SLOPE DATA ')        A04360
 370   FORMAT(//,15X,'NO. OF MESH POINTS IN CROSS-DIRECTION =',I5,       A04370
     #        //,15X,'NO. OF MESH POINTS IN LONGT-DIRECTION =',I5,       A04380
     #        //,15X,'AVERAGE SLOPE                         =',F5.1,     A04390
     # 3X,'DEGREES',/,T54,'=',F7.2,3X,'PERCENT',                         A04400
     #        //,15X,'RAINFALL INTENSITY                    =',F5.1,     A04410
     # 3X,'MLMTR/HR',//,15X,'RUNOFF COEFFICIENT                    =',   A04420
     # F5.2)                                                           A04430
 375   FORMAT(//,T16,'ANNUAL RAINFALL RATE',T54,'=',F5.1,T64,'CNTMTR',   A04440
     #        //,T16,'EQUIVALENT YEARS OF RAIN',T54,'=',F5.2,T64,'YEARS') A04450
 380   FORMAT(//,15X,'TIME INTERVAL                      =',F5.1,3X,     A04460
     #   'MINUTES',//,15X,'TOTAL RAIN PERIOD                 =',F5.2,   A04470
     # 3X,'HOURS',//,15X,'NO. OF RANDOM SURFACES             =',        A04480
     #   I5,//)                                                          A04490
 390   FORMAT(15X,'FAILURE  LIMIT FOR SIDE SLOPE', 9X,'=',F5.2,          A04500
     #     //,15X,'STARTING LIMIT FOR SIDE SLOPE', 9X,'=',F5.2,//)      A04510
 400   FORMAT(T23,'*',T26,' SPECTRAL ANALYSIS RESULTS ',T54,'*')         A04520
 250   STOP                                                              A04530
       END                                                               A04540
```

```
      SUBROUTINE STORE(NNOD,NHUMP)                                      B00010
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                B00020
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 B00030
      COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                        B00040
      WRITE(35)NY,NNOD,NHUMP                                            B00050
      WRITE(35) X(NMAX),Y(NY),SL                                        B00060
      DO 505 I=1,NMAX                                                   B00070
      IF(CODE(I).LE.0.0) GO TO 505                                      B00080
      WRITE(35)X(I),Y(I),ELV(I)                                         B00090
  505 CONTINUE                                                          B00100
      DO 620 I=1,NHUMP                                                  B00110
      WRITE(35)XHMP(I),YHMP(I),HHMP(I)                                  B00120
  620 CONTINUE                                                          B00130
      XEND=88888.                                                       B00140
      WRITE(35) XEND,YEND,ZEND                                          B00150
      RETURN                                                            B00160
      END                                                               B00170
      SUBROUTINE CWAVE(XP,YP,YYP,NP,NPF,CUT,TLEN,AMP,WL,RSD             C00010
     #,RMEAN,STDEV)                                                     C00020
C     ****************************************************************  C00030
C     THE FUNCTION OF THIS SUBPROGRAM IS:                               C00040
C     1) PROCESS SURFACE ROUGHNESS DATA FOR SPECTRAL ANALYSIS, AND      C00050
C     2) IDENTIFY THE BASIC WAVE                                        C00060
C                                                                       C00070
C     COMPUTATIONS ARE BASED ON THE METHOD OF AVERAGE COEFFICIENTS.     C00080
C     ****************************************************************  C00090
      REAL*8 FMEAN                                                      C00100
      REAL*4 XP(1),YP(1),YYP(1)                                         C00110
      REAL*8 AN(1000),BN(1000),DPOW(1000),R(1000),C(1000),WLAM(1000)    C00120
      REAL*8     AAN(1000),BBN(1000),RR(1000),CC(1000),DDPOW(1000)      C00130
      REAL*4 RSD(1000),YW(1000)                                         C00140
      DIMENSION NDEG(1000)                                              C00150
      NH1=NP/2+1                                                        C00160
      DO 401 I=1,NH1                                                    C00170
      AAN(I)=0.0                                                        C00180
      BBN(I)=0.0                                                        C00190
      DDPOW(I)=0.0                                                      C00200
      RR(I)=0.0                                                         C00210
      CC(I)=0.0                                                         C00220
  401 CONTINUE                                                          C00230
      DO 405  K=1,NPF                                                   C00240
      DO 404  I=1,NP                                                    C00250
      M=(K-1)*NP                                                        C00260
      YP(I)=YYP(M+I)                                                    C00270
  404 CONTINUE                                                          C00280
      CALL       FILTER(XP,YP,NP,NDEG,AN,BN,DPOW,R,C,WLAM,FMEAN)        C00290
C ... COMPUTE AVERAGE VALUES OF AN,BN,...,ETC FOR ALL PROFILES:         C00300
C                                                                       C00310
      DO 410 J=1,NH1                                                    C00320
      AAN(J)=AAN(J)+AN(J)/(1.*NPF)                                      C00330
      BBN(J)=BBN(J)+BN(J)/(1.*NPF)                                      C00340
      DDPOW(J)=DDPOW(J)+DPOW(J)/(1.*NPF)                                C00350
      RR(J)=RR(J)+R(J)/(1.*NPF)                                         C00360
      CC(J)=CC(J)+C(J)/(1.*NPF)                                         C00370
  410 CONTINUE                                                          C00380
  405 CONTINUE                                                          C00390
      WRITE(6,419)                                                      C00400
      WRITE(6,421)                                                      C00410
      WRITE(6,423)                                                      C00420
      WRITE(6,426)(NDEG(J),AAN(J),BBN(J),DDPOW(J),RR(J),CC(J),          C00430
     #  WLAM(J),J=1,NH1)                                                C00440
C                                                                       C00450
C ... DETERMINE THE BASIC WAVE : PICK-UP THE WAVE WITH MAX. POWER IN    C00460
C     THE "MICRO ROUGHNESS" RANGE.THE MICR. ROUGH. RANGE INCLUDES       C00470
C     ALL WAVES LENGTH LESS THAN OR EQUAL TO 30.0 CENTIMETERS.          C00480
C                                                                       C00490
      PWMAX=0.0                                                         C00500
      K=0                                                               C00510
      DO 430  I=1,NH1                                                   C00520
      IF(WLAM(I).GT.30.) GO TO 430                                      C00530
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      IF(DDPOW(I).LE.PWMAX)  GO TO 430                                  C00540
      PWMAX=DDPOW(I)                                                    C00550
      K=I                                                               C00560
  430 CONTINUE                                                          C00570
      AMP=(AAN(K)*AAN(K)+BBN(K)*BBN(K))**0.5                            C00580
      WL=WLAM(K)                                                        C00590
      PSI=2*NDEG(K)*22.0/7.0/TLEN                                       C00600
      DO 460 KK=1,NPF                                                   C00610
      DO 450 I=1,NP                                                     C00620
      M=(KK-1)*NP                                                       C00630
      YP(I)=YYP(M+I)                                                    C00640
      XPSI=XP(I)*PSI                                                    C00650
      FAZ1=COS(XPSI)                                                    C00660
      FAZ2=SIN(XPSI)                                                    C00670
      YW(I)=AAN(K)*FAZ1+BBN(K)*FAZ2+FMEAN                               C00680
      RSD(I)=YP(I)-YW(I)                                                C00690
  450 CONTINUE                                                          C00700
      CALL RESDL(RSD,NP,RMUE,SIGMA)                                     C00710
      RMEAN=RMEAN+RMUE/(1.*NPF)                                         C00720
      STDEV=STDEV+SIGMA/(1.*NPF)                                        C00730
C     WRITE(6,455) (RSD(I),I=1,NP)                                      C00740
  460 CONTINUE                                                          C00750
  419 FORMAT(     //,10X,'AVERAGE VALUES FOR ALL PROFILES',/)           C00760
  421 FORMAT(10X,31('*'))                                               C00770
  423 FORMAT(///,T6,'DEGREE',T16.'AN',T24,'BN',T32,'POWER',T40,'CONTR.',C00780
     #  T48,'TOTAL',T56,'L (CM)' /)                                     C00790
  425 FORMAT(2(I10,2F8.2,F11.3,2F8.4,F8.1,2X))                          C00800
  426 FORMAT(I10,2F8.2,F11.3,2F8.4,F8.2)                                C00810
  455 FORMAT(10(2X,F6.2))                                               C00820
      RETURN                                                            C00830
      END                                                               C00840
      SUBROUTINE FILTER(X ,Y ,N ,NDEG,AN,BN,DPOW,R,C,WLAM,FMEAN)        D00010
C     ******************************************************************D00020
C     THIS SUBPROGRAM PROCESSES THE DATA BEFORE AND AFTER SPECTRAL ANAL. D00030
C     IF MEASUREMENTS ARE NOT EQUALLY SPACED, THE PROGRAM GENERATES     D00040
C     AN INTERPOLATED PROFILE WITH INTERVAL=DX, USING THE FUNCTION TERP1.D00050
C     ******************************************************************D00060
C                                                                       D00070
      IMPLICIT REAL*8(A-H,O-Z)                                          D00080
      REAL*4 TLEN,CUT                                                   D00090
      REAL*4 X(1),Y(1)                                                  D00100
      REAL*4 YNS(1000),YORG(1000)                                       D00110
      REAL*4 XX(1000),YTEMP(1000)                                       D00120
      REAL*8  AN(1),BN(1),R(1),C(1)                                     D00130
      DIMENSION NDEG(1)                                                 D00140
      DIMENSION F(1000),DPOW(1000),WLAM(1000)                           D00150
      DIMENSION IL(2000),ILL(2000),ILLL(2000)                           D00160
      COMPLEX*16 FN(1000)                                               D00170
      EQUIVALENCE (IL(1),ILL(1),ILLL(1))                                D00180
      COMMON /SAME/TLEN,CUT                                             D00190
C ... INTERPOLATE TO HAVE EQUALLY SPACED DATA                           D00200
C     WRITE(6,720)                                                      D00210
C     WRITE(6,705)(X(I),Y(I),I=1,N)                                     D00220
C     WRITE(6,700)                                                      D00230
      DO 9  I=1,N                                                       D00240
       YORG(I)=Y(I)                                                     D00250
 9    CONTINUE                                                          D00260
      FINT=0.5                                                          D00270
      XX(1)=X(1)                                                        D00280
      F(1)=Y(1)                                                         D00290
      DELTA=TLEN/(N-1)                                                  D00300
      ABSIS=X(1)                                                        D00310
      DO 11 I=2,N                                                       D00320
      ABSIS=ABSIS+DELTA                                                 D00330
      XX(I)=ABSIS                                                       D00340
   11 F(I)=TERP1(ABSIS,X,Y,N,FINT)                                      D00350
C     WRITE(9,705)(XX(I),F(I),I=1,N)                                    D00360
C ... REMOVE THE MEAN                                                   D00370
      SUM=0.                                                            D00380
      DO 10 I=1,N                                                       D00390
   10 SUM=SUM+F(I)                                                      D00400
      FMEAN=SUM/N                                                       D00410
C     WRITE(6,715)FMEAN                                                 D00420
      DO 15 I=1,N                                                       D00430
   15 F(I)=F(I)-FMEAN                                                   D00440
C     WRITE(6,721)                                                      D00450
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C      WRITE(6,705)(XX(I),F(I),I=1,N)                                    D00460
C      WRITE(6,700)                                                      D00470
C ...  COMPUTE COMPLEX FOURIER COEFFICIENTS                              D00480
       CALL       POWER(F ,FN,NDEG,AN,BN,DPOW,R,C,WLAM,N)               D00490
C ...  COMPUTE DATA VECTOR IN TIME DOMAIN                                D00500
       NH=N/2                                                            D00510
       NH1=NH+1                                                          D00520
       NH2=NH+2                                                          D00530
C ...  FILTER OUT HIGH FREQUENCIES                                       D00540
C...   SPLIT  -FN(1)-  AND  -FN(NH1)-  INTO HALF TO USE FOLLOWING LOGIC  D00550
       FN(1)=FN(1)/2.                                                    D00560
       FN(NH1)=FN(NH1)/2.                                                D00570
       DO 16 I=2,NH1                                                     D00580
       IF(DABS(WLAM(I)).LT.CUT)GO TO 100                                 D00590
    16 CONTINUE                                                          D00600
   100 CONTINUE                                                          D00610
       NHIGH=I                                                           D00620
       IF(I.EQ.NH1)NHIGH=I+1                                             D00630
       DO 20 I=NHIGH,N                                                   D00640
    20 FN(I)=(0.,0.)                                                     D00650
C ...  COMPUTE INVERSE FOURIER TRANSFORM                                 D00660
       CALL FFTP(FN,N,IL,ILL,ILLL)                                       D00670
       DO 25 I=1,N                                                       D00680
    25 FN(I)=FN(I)+DCONJG(FN(I))                                         D00690
       DO 26 I=1,N                                                       D00700
    26 F(I)=FN(I)+FMEAN                                                  D00710
       DO 30 I=1,N                                                       D00720
    30 YTEMP(I)=F(I)                                                     D00730
       DO 35 I=1,N                                                       D00740
       ABSIS=X(I)                                                        D00750
    35 Y(I)=TERP1(ABSIS,XX,YTEMP,N,FINT)                                 D00760
C      WRITE(6,700)                                                      D00770
C      WRITE(6,722)                                                      D00780
C      WRITE(6,705)(XX(I),Y(I),I=1,N)                                    D00790
C....COMPUTE FILTERED-OUT  DATA"YNS"                                     D00800
       DO 36 I=1,N                                                       D00810
       YNS(I)=YORG(I)-F(I)                                               D00820
 36    CONTINUE                                                          D00830
C      WRITE(6,700)                                                      D00840
C      WRITE(6,705)(XX(I),YNS(I),I=1,N)                                  D00850
C      WRITE(6,723)                                                      D00860
  700 FORMAT(//////)                                                     D00870
  705 FORMAT(5(2F10.2,5X))                                               D00880
  715 FORMAT(///,'          MEAN VALUE =',F10.3,' MLMTR',///)            D00890
  720 FORMAT(///,55X,'ORIGINAL  DATA',//)                                D00900
  721 FORMAT( 55X, 'REMOVED-MEAN  DATA',//)                              D00910
  722 FORMAT( 55X, 'FILTERED  DATA',//)                                  D00920
  723 FORMAT( 55X,'FILTERED-OUT  DATA',//)                               D00930
       RETURN                                                            D00940
       END                                                               D00950
       SUBROUTINE POWER(F ,FN,NDEG,AN,BN,DPOW,R,C,WLAM,N)                E00010
C      ******************************************************************E00020
C      THIS SUBPROGRAM PERFORMS SPECTRAL ANALYSIS ON SURFACE ROUGHNESS   E00030
C      MEASUREMENTS                                                      E00040
C      ******************************************************************E00060
C                                                                        E00070
       IMPLICIT REAL*8(A-H,O-Z)                                          E00080
       REAL*4 CUT,TLEN                                                   E00090
       DIMENSION F(1),DPOW(1),WLAM(1)                                    E00100
       DIMENSION AN(1000),BN(1000),NDEG(1000),S(1000),C(1000),R(1000)    E00110
       DIMENSION IWK(2000)                                               E00120
       COMPLEX*16 GAMN,FN(1)                                             E00130
       COMMON /SAME/TLEN,CUT                                             E00140
C ......                                                                 E00150
       NH=N/2                                                            E00160
       NH1=NH+1                                                          E00170
C ...  COMPUTE THE VARIANCE OF THE SIGNAL                                E00180
       VAR1=0.                                                           E00190
       DO 10 I=1,N                                                       E00200
    10 VAR1=VAR1+F(I)**2                                                 E00210
       VAR1=VAR1/N                                                       E00220
C ...  COMPUTE COMPLEX FOURIER COEFFICIENTS OF  -F-  BY FFT              E00230
       CALL FFTR(F,GAMN,N,IWK)                                           E00240
C ...   TAKE CONJUGATE OF OUTPUT AND DIVIDE BY  N  TO GET INV. FFT      E00250
       FN(1)=DCMPLX(F(1),-F(2))/N                                        E00260
       DO 15 I=2,NH                                                      E00270
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      II=2*I                                                            E00280
      FN(I)=DCMPLX(F(II-1),-F(II))/N                                    E00290
   15 FN(N+2-I)=DCONJG(FN(I))                                           E00300
      FN(NH1)=DCONJG(GAMN)/N                                            E00310
C ... COMPUTE  -AN-  AND  -BN-  COEFFICIENTS                            E00320
      AN(1)=FN(1)                                                       E00330
      WLAM(I)=0                                                         E00340
      DO 16 I=2,NH                                                      E00350
      AN(I)=2.*FN(I)                                                    E00360
      BN(I)=2.*DIMAG(FN(I))                                             E00370
      WLAM(I)=TLEN/(I-1)                                                E00380
   16 CONTINUE                                                          E00390
      AN(NH1)=FN(NH1)                                                   E00400
      WLAM(NH1)=TLEN/NH                                                 E00410
C ... COMPUTE DEGREE POWER,CONTRIBUTION ETC....                         E00420
      VAR2=0.                                                           E00430
      BN(1)=0.                                                          E00440
      BN(NH1)=0.                                                        E00450
      DO 17 I=1,NH1                                                     E00460
      NDEG(I)=I-1                                                       E00470
      DPOW(I)=(AN(I)**2+BN(I)**2)/2.D0                                  E00480
      IF(I.EQ.1.OR.I.EQ.NH1)DPOW(I)=2.*DPOW(I)                          E00490
      VAR2=VAR2+DPOW(I)                                                 E00500
      S(I)=VAR2                                                         E00510
   17 CONTINUE                                                          E00520
      SUM=VAR2                                                          E00530
      R(1)=0.                                                           E00540
      C(1)=0.                                                           E00550
      DO 20 I=2,NH1                                                     E00560
      R(I)=DPOW(I)/VAR2                                                 E00570
      C(I)=S(I)/VAR2                                                    E00580
   20 CONTINUE                                                          E00590
C     WRITE(6,700)                                                      E00600
C     WRITE(6,705)(NDEG(I),AN(I),BN(I),DPOW(I),R(I),C(I),WLAM(I),I=1,NH1 E00610
C    #)                                                                 E00620
      DPOW(1)=FN(1)*DCONJG(FN(1))                                       E00630
C     WRITE(6,710)VAR1,VAR2                                             E00640
C     FIND THE POWER FROM COMPLEX FOURIER COEFF. TO CHECK THE RESULT    E00650
      DO 25 I=2,NH                                                      E00660
      DPOW(I)=2.*(FN(I)*DCONJG(FN(I)))                                  E00670
      DPOW(NH1)=FN(NH1)*DCONJG(FN(NH1))                                 E00680
   25 CONTINUE                                                          E00690
C     WRITE(9,700)                                                      E00700
C     WRITE(9,705)(NDEG(I),AN(I),BN(I),DPOW(I),R(I),C(I),WLAM(I),I=1,NH1 E00710
C    *)                                                                 E00720
  700 FORMAT(///,T6,'DEGREE',T16,'AN',T24,'BN',T32,'POWER',T40,'CONTR.', E00730
     *T48,'TOTAL',T56,'L (CM)',T69,'DEGREE',T79,'AN',T87,'BN',T95,'POWER E00740
     *',T103,'CONTR.',T111,'TOTAL',T119,'L (CM)',/)                      E00750
  705 FORMAT(2(I10,2F8.2,F11.3,2F8.4,F8.1,2X))                          E00760
  710 FORMAT(/30X,'TOTAL POWER IN TIME DOMAIN=',F17.5,' MLMTR**2',/,30X, E00770
     *'TOTAL POWER IN FREQ.DOMAIN=',F17.5,' MLMTR**2',//)               E00780
      RETURN                                                            E00790
      END                                                               E00800
      FUNCTION TERP1(X,XI,YI,N,F)                                       F00010
C     ********************************************************************F00020
C     THIS SUBPROGRAM PRODUCES AN EQUALLY SPACED PROFILE (IF            F00030
C     MEASUREMENTS WERE NOT SO)                                         F00040
C                                                                       E00050
C     ********************************************************************F00050
C                                                                       F00060
      IMPLICIT REAL*8(A-H,O-Z)                                          F00070
      REAL*4 XI(1),YI(1)                                                F00080
C     X IS THE INDEPENDENT VARIABLE                                     F00090
C     XI   IS AN ARRAY OF VALUES OF THE INDEPENDENT VARIABLE            F00100
C     YI  IS AN ARRAY OF CORRESPONDING VALUES OF DEPENDENT VARIABLE     F00110
C     N IS THE SIZE OF THE ARRAYS                                       F00120
C     F IS A FACTOR FOR THE END SEGMENTS; BALANCE OF FIRST OND SECOND   F00130
C          ORDER INTERPOLATION                                          F00140
C     ALL VALUES  OUTSIDE THE LIMITS OF THE ARRAY ARE COMPUTED BY       F00150
C        FIRST ORDER EXTRAPOLATION                                      F00160
C     FUNCTION RETURNS INTERPOLATED VALUE OF DEPENDENT VARIABLE         F00170
      DIMENSION P(2),E(2),IS(4,2)                                       F00180
      LOGICAL OUT                                                       F00190
      DATA IS   /-1,0,-2,-1,0,1,-1,0/                                   F00200
      OUT = .FALSE.                                                     F00210
      J=1                                                               F00220
```

```
      IF (N-2) 1,12,3                                                    F00230
    1 TERP1=YI(J)                                                        F00240
      RETURN                                                             F00250
    3 KPL=1                                                              F00260
      KPU=2                                                              F00270
      DO 4 J=1,N                                                         F00280
    7 IF (XI(J) - X) 4,1,6                                               F00290
    4 CONTINUE                                                           F00300
      J = N                                                              F00310
      GO TO 2                                                            F00320
    6 IF (J-2) 12,8,9                                                    F00330
    8 KPL =2                                                             F00340
      GO TO 10                                                           F00350
    9 IF (J - N) 10,11,2                                                 F00360
   12 J=2                                                                F00370
    2 OUT=.TRUE.                                                         F00380
   11 KPU=1                                                              F00390
   10 AL = (X-XI(J-1)) /(XI(J)-XI(J-1))                                  F00400
      TERP1=AL*YI(J)+(1.0-AL)*YI(J-1)                                    F00410
      IF (OUT) RETURN                                                    F00420
      DO 16 KP=KPL,KPU                                                   F00430
       P(KP)=0.0                                                         F00440
       DO 15 K=1,3                                                       F00450
        J0=J+KP + K - 4                                                  F00460
        X0=XI(J0)                                                        F00470
        Y0=YI(J0)                                                        F00480
        J1=J+IS(K,KP)                                                    F00490
        J2=J+IS(K+1,KP)                                                  F00500
   15   P(KP)=P(KP)+Y0*(X-XI(J1))/(X0-XI(J1))                           F00510
     *                 *(X-XI(J2))/(X0-XI(J2))                         F00520
       IF (KPL .NE. KPU) GO TO 16                                        F00530
      J1=3-KPL                                                           F00540
      P(J1)=TERP1+F*(P(KP)-TERP1)                                        F00550
C ...                                                                    F00560
C .. BE CAREFUL FOR FOLLOWING CARDS IF ..ABS..OR ..DABS...               F00570
      E(J1)=DABS(P(J1)-TERP1)                                            F00580
    16 E(KP)=DABS(P(KP)-TERP1)                                           F00590
       IF (E(1)+E(2) .EQ. 0.0) RETURN                                    F00600
      TERP1=((E(1)*AL)*P(2)+(E(2)*(1.0-AL))*P(1)) /                      F00610
     *       ((E(1)*AL)      +(E(2)*(1.0-AL))      )                    F00620
      RETURN                                                             F00630
      END                                                                F00640
      SUBROUTINE RESDL(RSD,NP,RMEAN,STDEV)                               G00010
C     ********************************************************************G00020
C     THIS SUBPROGRAM COMPUTES THE MEAN AND THE STANDARD DEVIATION OF    G00030
C     THE NORMALLY DISTRIBUTED RESIDUAL DATA.                            G00040
C     ********************************************************************G00050
C                                                                        G00060
      DIMENSION RSD(200)                                                 G00070
C ... COMPUTE MEAN                                                       G00080
      SUM=0.0                                                            G00090
      DO 101 I=1,NP                                                      G00100
      SUM=SUM+RSD(I)                                                     G00110
  101 CONTINUE                                                           G00120
      RMEAN=SUM/NP                                                       G00130
C ... COMPUTE THE VARIANCE                                               G00140
      SUMV=0.0                                                           G00150
      DO 102 I=1,NP                                                      G00160
      SUMV=SUMV+(RSD(I)-RMEAN)*(RSD(I)-RMEAN)                            G00170
  102 CONTINUE                                                           G00180
      VARV=SUMV/NP                                                       G00190
      SD=VARV**0.5                                                       G00200
      STDEV=ABS(SD)                                                      G00210
      RETURN                                                             G00220
      END                                                                G00230
```

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      SUBROUTINE PARAM(D,P,ASR,ASH,RCH,HCH,EX)                          H00010
C     ****************************************************************  H00020
C     THIS SUBPROGRAM USES THE PROBLEM PARAMETERS TO COMPUTE THE MAIN   H00030
C     COEFFICIENTS IN EROSION EQUATIONS.                                H00040
C     GAMA = UNIT WEIGHT OF SOIL                                        H00050
C     SG   = SPECIFIC WEIGHT OF SOIL                                    H00060
C       RO = WATER DENSITY                                              H00070
C        G = GRAVITY ACCELERATION                                       H00080
C       RN = MANNING'S COEFFICIENT OF FRICTION                          H00090
C     ****************************************************************  H00100
C                                                                       H00110
      COMMON /PROP/GAMA,RO,G,SG,RN                                      H00120
      Z=(((SG-1.)*G)**P)*(D**(P-1))                                     H00130
      RBETA=ASR/Z                                                       H00140
      HBETA=ASH/Z                                                       H00150
      X=(1.+2.*P)/2.                                                    H00160
      RCH=RBETA*(1.+2.*P)/2./RO**X                                      H00170
      HCH=HBETA*(1.+2.*P)/2./RO**X                                      H00180
      EX=(2.*P-1.)/2.                                                   H00190
      RETURN                                                            H00200
      END                                                               H00210
      SUBROUTINE  RANDU(IX,IY,R)                                        I00010
C     ****************************************************************  I00020
C     THIS SUBPROGRAM GENERATES A RANDOM NUMBER WITH VALUE 0.0 TO 1.0   I00030
C     FROM A UNIFORM DISTRIBUTION                                       I00040
C     ****************************************************************  I00050
C                                                                       I00060
      IY=IX*65539                                                       I00070
      IF(IY)5,6,6                                                       I00080
    5 IY=IY+2147483647+1                                                I00090
    6 R=IY                                                              I00100
      R=R*0.465613E-9                                                   I00110
      RETURN                                                            I00120
      END                                                               I00130
      SUBROUTINE RANORM(NMAX,RMEAN,STDEV,RY,NS)                         J00010
C     ****************************************************************  J00020
C     IT GENERATES NORMALLY DISTRIBUTED RANDOM NUMBERS FOR THE GIVEN    J00030
C     MEAN AND STANDARD DEVIATION                                       J00040
C     ****************************************************************  J00050
C                                                                       J00060
      DIMENSION RY(2000)                                                J00070
      IF(NS.GT.1) GO TO 800                                             J00080
      IX=123456789                                                      J00090
  800 DO 810 I=1,NMAX                                                   J00100
      SUM=0.0                                                           J00110
      DO 820 K=1,12                                                     J00120
      CALL   RANDU(IX,IY,R)                                             J00130
      IX=IY                                                             J00140
      SUM=SUM+R                                                         J00150
  820 CONTINUE                                                          J00160
      X=(SUM-6.0)*STDEV+RMEAN                                           J00170
      RY(I)=X                                                           J00180
  810 CONTINUE                                                          J00190
C     WRITE(6,12)(I,RY(I),I=1,NMAX)                                     J00200
   12 FORMAT(I5,5X,F10.6)                                               J00210
      RETURN                                                            J00220
      END                                                               J00230
      SUBROUTINE HXMESH                                                 K00010
C     ****************************************************************  K00020
C     THIS SUBPROGRAM CALCULATES THE COORDINATES AND ASSIGNS CODES      K00030
C     FOR NODAL POINTS OF THE HEXAGONAL MESH                            K00040
C     FOR BIFURCATION POINTS,CODE=2 ,                                   K00050
C     FOR NON-BIFURCATION POINTS ,CODE=1,AND                            K00060
C     FOR OTHER POINTS CODE=0                                           K00070
C     THE X-Y PLANE COINSIDES WITH THE SLOPE SURFACE.                   K00080
C     MESH DIMENSIONS ARE BASED ON CHARACTERISTICS OF BASIC WAVE        K00090
C     ****************************************************************  K00100
C                                                                       K00110
      DIMENSION XX(2000)                                                K00120
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                K00130
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 K00140
C ... COMPUTE X AND Y COORDINATES OF NODAL POINTS                       K00150
      NMAX=NX*NY                                                        K00160
      J=1                                                               K00170
      XX(J)=0                                                           K00180
```

```
      NS=1                                                              K00190
      NE=NY                                                             K00200
   11 DO 10 I=NS,NE,2                                                   K00210
      K=I+1                                                             K00220
      IF(I.EQ.1) GO TO 15                                               K00230
      IF(I.EQ.NS) GO TO 16                                              K00240
      IF(K.GT.NE) GO TO 17                                              K00250
      Y(I)=Y(I-1)+ SL                                                   K00260
      Y(K)=Y(I)+2*SL                                                    K00270
      X(K)=XX(J)                                                        K00280
      X(I)=XX(J)                                                        K00290
      GO TO 10                                                          K00300
   15 Y(I)=0                                                            K00310
      Y(2)=Y(1)+2*SL                                                    K00320
      X(1)=XX(J)                                                        K00330
      X(2)=XX(J)                                                        K00340
      GO TO 10                                                          K00350
   16 Y(NS)=0                                                           K00360
      Y(NS+1)=Y(NS)+2*SL                                                K00370
      X(NS)=XX(J)                                                       K00380
      X(NS+1)=XX(J)                                                     K00390
      GO TO 10                                                          K00400
   17 Y(I)=Y(I-1)+ SL                                                   K00410
      X(I)=X(I-1)                                                       K00420
   10 CONTINUE                                                          K00430
      J=J+1                                                             K00440
      IF(J.GT.NX) GO TO 1000                                            K00450
      XX(J)=XX(J-1)+WL/2.                                               K00460
      NE=NE+NY                                                          K00470
      NS=NS+NY                                                          K00480
      IF(NE.GT.NMAX) GO TO 1000                                         K00490
      GO TO 11                                                          K00500
 1000 M=NY                                                              K00510
C ... ASSIGN CODES TO NODAL POINTS                                      K00520
      MAX=2*NY                                                          K00530
      K=1                                                               K00540
      DO 30 J=K,M,4                                                     K00550
      DO 30 I=J,NMAX,MAX                                                K00560
      CODE(I)=2                                                         K00570
   30 CONTINUE                                                          K00580
      M=2*NY                                                            K00590
      K=NY+3                                                            K00600
      DO 40 J=K,M,4                                                     K00610
      DO 40 I=J,NMAX,MAX                                                K00620
      CODE(I)=2                                                         K00630
   40 CONTINUE                                                          K00640
      M=NY                                                              K00650
      K=2                                                               K00660
      DO 50 J=K,M,4                                                     K00670
      DO 50 I=J,NMAX,MAX                                                K00680
      CODE(I)=1                                                         K00690
   50 CONTINUE                                                          K00700
      M=2*NY                                                            K00710
      K=NY+4                                                            K00720
      DO 60 J=K,M,4                                                     K00730
      DO 60 I=J,NMAX,MAX                                                K00740
      CODE(I)=1                                                         K00750
   60 CONTINUE                                                          K00760
      RETURN                                                            K00770
      END                                                               K00780
      SUBROUTINE ELEVTN(SLOPE,AMP,RMEAN,STDEV,NS)                       L00010
C     ****************************************************************  L00020
C                                                                       L00030
C     THIS SUBPROGRAM CALCULATES THE ORIGINAL (PRE-EROSION) ELEVATIONS  L00040
C     OF NODAL POINTS                                                   L00050
C     ELEVATION OF EACH NODAL POINT IS COMPUTED AS THE SUM OF THE       L00060
C     FOLLOWING COMPONENTS                                              L00070
C     1) FROM THE AVERAGE SLOPE                                         L00080
C     2) FROM THE BASIC WAVE,WY                                         L00090
C     3) RESIDUAL COMPONENT GENERATED RANDOMLY ,RY                      L00100
C     ****************************************************************  L00110
C                                                                       L00120
      DIMENSION RY(2000)                                                L00130
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                L00140
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 L00150
      PI=22.0/7.0                                                       L00160
      THETA=SLOPE*PI/180                                                L00170
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      L=1                                                                L00180
      PHI=PI*(1./6.)                                                     L00190
      WY=AMP*SIN(PHI)*COS(THETA)                                         L00200
      DO 700 I=1,NMAX                                                    L00210
  700 RY(I)=0.0                                                          L00220
      CALL        RANORM(NMAX,RMEAN,STDEV,RY,NS)                         L00230
C     CALL        RANORM(NMAX,RMEAN,STDEV,RY,NS)                         L00240
      DO 710  M=NY,NMAX,NY                                               L00250
      DO 720 I=L,M,4                                                     L00260
      ELV(I)=Y(I)*SIN(THETA)-WY+RY(I)                                    L00270
      IF(Y(I).EQ.Y(NY)) GO TO 730                                        L00280
      ELV(I+1  )=Y(I+1)*SIN(THETA)-WY+RY(I+1)                            L00290
      IF(Y(I+1).EQ.Y(NY)) GO TO 730                                      L00300
      ELV(I+2)  =Y(I+2)*SIN(THETA)+WY+RY(I+2)                            L00310
      IF(Y(I+3).EQ.Y(NY))ELV(I+3)  =Y(I+3)*SIN(THETA)+WY+RY(I+3)         L00320
  730 IF(Y(I).EQ.0) GO TO 720                                            L00330
      ELV(I-1)  =Y(I-1)*SIN(THETA)+WY+RY(I-1)                            L00340
  720 CONTINUE                                                           L00350
      L=L+NY                                                             L00360
      WY=-WY                                                             L00370
  710 CONTINUE                                                           L00380
C     WRITE(6,790)(I,X(I),Y(I),RY(I),ELV(I),I=1,NMAX)                    L00390
  790 FORMAT(10X,I5,4F10.6)                                              L00400
      RETURN                                                             L00410
      END                                                                L00420
      SUBROUTINE HUMP(RMEAN,STDEV,SLOPE,AMP,NHUMP)                       M00010
C     ************************************************************       M00020
C     THIS SUBPROGRAM COMPUTES COORDINATES AND ELEVATIONS OF CIRCULAR    M00030
C     HUMPS' CENTERS.                                                    M00040
C     ************************************************************       M00050
C                                                                        M00060
      DIMENSION  RHY(500)                                                M00070
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                 M00080
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                  M00090
      COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                         M00100
      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),   M00110
     #  HMP6(500)                                                        M00120
C                                                                        M00130
C ... DETERMINE THE TOTAL NUMBER OF HUMPS ,NHUMP                         M00140
      NZ=NY+1                                                            M00150
      M1=NZ/4                                                            M00160
      RM1=1.*NZ/4                                                        M00170
      DM1=RM1-M1                                                         M00180
      IF(DM1.GT.0.AND.DM1.LE.0.5) GO TO 1210                             M00190
      GO TO 1220                                                         M00200
 1210 NHUMP=M1*NX                                                        M00210
      GO TO 1225                                                         M00220
 1220 N1=NX/2                                                            M00230
      RN1=1. * NX/2.0                                                    M00240
      DN1=RN1-N1                                                         M00250
      IF(DM1.EQ.0) GO TO 1230                                            M00260
      IF(DN1.EQ.0) GO TO 1231                                            M00270
      NHUMP=2*M1*N1 +N1+M1                                               M00280
      GO TO 1225                                                         M00290
 1231 NHUMP=N1*(2*M1+1)                                                  M00300
      GO TO 1225                                                         M00310
 1230 IF(DN1.EQ.0) GO TO 1235                                            M00320
      NHUMP= 2*N1*M1-N1+M1-1                                             M00330
      GO TO 1225                                                         M00340
 1235 NHUMP=N1*(2*M1-1)                                                  M00350
      GO TO 1225                                                         M00360
 1225 CONTINUE                                                           M00370
C                                                                        M00380
C ... COMPUTE X AND Y COORDINATES                                        M00390
      K=1                                                                M00400
      DO 1250 I=1,NMAX                                                   M00410
      IF(CODE(I)-1) 1260,1270,1270                                       M00420
 1270 GO TO 1250                                                         M00430
 1260 IF(CODE(I-1).NE.0) GO TO 1250                                      M00440
      IF(Y(I-1).EQ.Y(NY)) GO TO 1250                                     M00450
      XHMP(K)=X(I)                                                       M00460
      YHMP(K)=(Y(I)+Y(I-1))/2.0                                          M00470
      K=K+1                                                              M00480
 1250 CONTINUE                                                           M00490
C                                                                        M00500
C ... COMPUTE ELEVATIONS                                                 M00510
      CALL        RANORM(NHUMP,RMEAN,STDEV,RHY)                          M00520
C     CALL        RANORM(NHUMP,RMEAN,STDEV,RHY)                          M00530
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      A=AMP*COS(SLOPE*22./7./180.)                                          M00340
      DO 1280 I=1,NHUMP                                                     M00550
      HHMP(I)=(YHMP(I)+2.*SL)*SIN(SLOPE*22./7./180.)+A  +RHY(I)             M00560
 1280  CONTINUE                                                            M00570
C     WRITE(6,1290)(I,XHMP(I),YHMP(I),HHMP(I),   I=1,NHUMP)                M00580
 1290 FORMAT(I5,3F20.6)                                                     M00590
C                                                                           M00600
C ... COMPUTE "FICTICIOUS" ELEVATIONS OF THE HUMP CENTER FOR EACH OF        M00610
C     THE SIX SIDES OF THE "PYRAMID"                                        M00620
      DO 1295  I=1,NHUMP                                                    M00630
      HMP1(I)=HHMP(I)                                                       M00640
      HMP2(I)=HHMP(I)                                                       M00650
      HMP3(I)=HHMP(I)                                                       M00660
      HMP4(I)=HHMP(I)                                                       M00670
      HMP5(I)=HHMP(I)                                                       M00680
      HMP6(I)=HHMP(I)                                                       M00690
 1295 CONTINUE                                                              M00700
      RETURN                                                                M00710
      END                                                                   M00720
      SUBROUTINE IDHMP(NY,I,IDL,IDR,IDC)                                    N00010
C     ********************************************************************* N00020
C     THIS SUBPROGRAM IDENTIFIES THE HUMPS ASSOCIATED WITH DIFFERENT        N00030
C     RILL SEGMENTS                                                         N00040
C     IDL=CALL# OF HUMP LEFT OF I                                           N00050
C     IDR=CALL# OF HUMP RIGHT OF I                                          N00060
C     IDC=CALL# OF HUMP BELOW I (IF CODE(I)=2)                              N00070
C     NC= # COMPLETE MESH COLUMNS BEFORE I                                  N00080
C     NHB=# OF HUMPS BELOW I                                                N00090
C     ********************************************************************* N00100
C                                                                           N00110
      COMMON NT                                                             N00120
      NZ=NY+1                                                               N00130
      M=NZ/4                                                                N00140
      RM=1.*NZ/4.                                                           N00150
      DM=RM-M                                                               N00160
      KD=DM*4+1                                                             N00170
      NC=I/NY                                                               N00180
      RNC=(1.*I)/(1.*NY)                                                    N00190
      IF(RNC.GT.NC) GO TO 1501                                              N00200
      NC=NC-1                                                               N00210
 1501 NHB=((I+NC+1)-(NC*NZ))/4                                              N00220
      IF(I.LT.NY) GO TO 1505                                                N00230
      INC=NC/2                                                              N00240
      RRNC=1.*NC/2.                                                         N00250
      IF(RRNC.EQ.INC) GO TO 1505                                            N00260
      GO TO (1510,1515,1515,1520),KD                                        N00270
 1510 IDL=(NC-1)/2*M+(NC-1)/2*(M-1)+NHB                                     N00280
      GO TO 1530                                                            N00290
 1515 IDL=(NC-1)*M+NHB                                                      N00300
      GO TO 1535                                                            N00310
 1520 IDL=(NC-1)/2*(M+1)+(NC-1)/2*M+NHB                                     N00320
      GO TO 1540                                                            N00330
 1530 IDR=(NC+1)/2*M+(NC+1)/2*(M-1)+NHB                                     N00340
      GO TO 1550                                                            N00350
 1535 IDR=(NC+1)*M+NHB                                                      N00360
      GO TO 1555                                                            N00370
 1540 IDR=(NC+1)/2*(M+1)+(NC+1)/2*M+NHB                                     N00380
      GO TO 1560                                                            N00390
 1550 IDC=(NC/2+1)*(M-1)+(NC/2)*M+NHB                                       N00400
      GO TO 1595                                                            N00410
 1555 IDC=NC*M+NHB                                                          N00420
      GO TO 1595                                                            N00430
 1560 IDC=(NC/2+1)*M+NC/2*(M+1)+NHB                                         N00440
      GO TO 1595                                                            N00450
 1505 GO TO (1570,1575,1575,1580),KD                                        N00460
 1570 IDL=((NC-1)/2+1)*(M-1)+(NC-1)/2*M+NHB+1                               N00470
      GO TO 1573                                                            N00480
 1575 IDL=(NC-1)*M+NHB+1                                                    N00490
      GO TO 1578                                                            N00500
 1580 IDL=((NC-1)/2+1)*M+(NC-1)/2*(M+1)+NHB+1                               N00510
      GO TO 1585                                                            N00520
 1573 IDR=((NC+1)/2+1)*(M-1)+(NC+1)/2*M+NHB+1                               N00530
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      GO TO 1574                                                        N00540
 1578 IDR=(NC+1)*M+NHB+1                                                N00550
      GO TO 1579                                                        N00560
 1585 IDR=((NC+1)/2+1)*M+(NC+1)/2*(M+1)+NHB+1                           N00570
      GO TO 1590                                                        N00580
 1574 IDC=(NC/2)*M+(NC/2)*(M-1)+NHB                                     N00590
      GO TO 1595                                                        N00600
 1579 IDC=NC*M+NHB                                                      N00610
      GO TO 1595                                                        N00620
 1590 IDC=(NC/2)*(M+1)+(NC/2)*M+NHB                                     N00630
 1595 CONTINUE                                                          N00640
      RETURN                                                            N00650
      END                                                               N00660
      SUBROUTINE FLOW(RNL,RNF)                                          000010
C     ****************************************************************  000020
C     FLOW RATE IN A RILL SEGMENT IS THE SUM OF :                       000030
C     1) DIRECT RAINFALL ON SURFACES OF RILL AND INTERRILL AREAS ,AND   000040
C     2) FLOW ARRIVING FROM AREA UPSLOPE                                000050
C                                                                       000060
C     AT A BIFURCATION POINT THE FLOW IS DEVIDED BETWEEN THE LEFT AND   000070
C     THE RIGHT BRANCH ACCORDING TO THE RELATIVE MAGNITUDES OF BED      000080
C     SLOPES RAISED TO THE POWER OF 0.5 .                               000090
C                                                                       000100
C     QT(I) IS THE AMOUNT OF WATER ACCUMULATED AT POINT I               000110
C    QR(I) IS THE AMOUNT OF WATER BRANCHING OUT FROM POINT I            000120
C    QL(I) IS THE AMOUNT OF WATER BRANCHING OUT FROM POINT I            000130
C     FLOW QUANTITY IS IN CUBIC METERS/SEC.                             000140
C                                                                       000150
C     IF A "LOW" HUMP OOCCURS, THE FLOW IS REDITRIBUTED IN (RDISTB).    000160
C     ****************************************************************  000170
C                                                                       000180
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                000190
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 000200
      COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)                        000210
      COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                        000220
      COMMON/QFLOW/QT(2000),QL(2000),QR(2000)                           000230
      COMMON NT                                                         000240
C                                                                       000250
C     COMPUTE RAINFALL FLOW RATE / UNIT TIME / UNIT AREA :              000260
C                                                                       000270
      QQ=(RNF*RNL)/(3.6*10**6)                                          000280
C     DQ IS THE AMOUNT OF WATER DRAINED TO A RILL SEGMENT FROM BOTH SIDES 000290
C     PER UNIT TIME.                                                    000300
      DQ=2.*QQ*SL*SL*(3.**0.5)                                          000310
C                                                                       000320
C     COMPUTE TOTAL FLOW RATE AT EACH NODAL POINT :                     000330
C                                                                       000340
      DO 901 L=1,NY                                                     000350
      K=NY+(1-L)                                                        000360
      DO 901 I=K,NMAX,NY                                                000370
      IF(CODE(I)-1)  902,903,904                                        000380
C                                                                       000390
C     POINTS WITH CODE=0 :                                              000400
C                                                                       000410
  902 QR(I)=0                                                           000420
      QL(I)=0                                                           000430
      QT(I)=0                                                           000440
      GO TO 901                                                         000450
C                                                                       000460
C     POINTS WITH CODE=1 :                                              000470
C                                                                       000480
 903  IF(Y(I).LT.Y(NY)) GO TO 905                                       000490
      GO TO 902                                                         000500
 905  IF(X(I).EQ.0) GO TO 915                                           000510
      SLL=(ELV(I-NY+1)  -ELV(I)  )/2.0/SH                               000520
      IF(X(I).EQ.X(NMAX)) GO TO 907                                     000530
 915  SLR=(ELV(I+NY+1  )-ELV(I  ))/2.0/SH                               000540
      IF(X(I).EQ.0) GO TO 906                                           000550
      IF(X(I).GE.X(NMAX)) GO TO 907                                     000560
      IF(SLL.LE.0.AND.SLR.LE.0) GO TO 908                               000570
      IF(SLL.LE.0.AND.SLR.GT.0) GO TO 909                               000580
      IF(SLL.GT.0.AND.SLR.LE.0) GO TO 910                               000590
      QT(I)=QT(I)+QR(I-NY+1)+QL(I+NY+1)+2*DQ                            000600
      CALL       RDISTB(I,CODE(I))                                      000610
      GO TO 901                                                         000620
  908 QT(I)=0                                                           000630
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      GO TO 901                                                          000640
  909 QT(I)=QT(I)+QR(I-NY+1)+DQ                                          000650
      CALL        RDISTB(I,CODE(I))                                      000660
      GO TO 901                                                          000670
  910 QT(I)=QT(I)+QL(I+NY+1)+DQ                                          000680
      CALL        RDISTB(I,CODE(I))                                      000690
      GO TO 901                                                          000700
  906 IF(SLR.LE.0.0) GO TO 911                                           000710
      QT(I)=QT(I)+QL(I+NY+1)+DQ                                          000720
      CALL        RDISTB(I,CODE(I))                                      000730
      GO TO 901                                                          000740
  911 QT(I)=0.0                                                          000750
      GO TO 901                                                          000760
  907 IF(SLL.LE.0.0) GO TO 911                                           000770
      QT(I)=QT(I)+QR(I-NY+1)+DQ                                          000780
      CALL        RDISTB(I,CODE(I))                                      000790
      GO TO 901                                                          000800
C                                                                        000810
C     POINTS OF CODE=2 (BIFURCATION POINTS)                              000820
C                                                                        000830
  904 IF(Y(I).EQ.Y(NY)) GO TO 902                                        000840
      SLM=(ELV(I+1  )-ELV(I  ))/2.0/SH                                   000850
      IF(SLM.GT.0) GO TO 916                                             000860
      QT(I)=0                                                            000870
      GO TO 902                                                          000880
  916 IF(X(I).EQ.0) GO TO 930                                            000890
      IF(X(I).EQ.X(NMAX)) GO TO 940                                      000900
      QT(I)=QT(I)+QT(I+1)+DQ                                             000910
      SLL=(ELV(I  )-ELV(I-NY-1  ))/2.0/SH                                000920
      SLR=(ELV(I  )-ELV(I+NY-1  ))/2.0/SH                                000930
      IF(SLL.LE.0.AND.SLR.LE.0) GO TO 920                                000940
      IF(SLL.LE.0.AND.SLR.GT.0) GO TO 921                                000950
      IF(SLL.GT.0.AND.SLR.LT.0) GO TO 922                                000960
      SLL1=(ELV(I-NY-1)-ELV(I-NY-2))/2.0/SH                              000970
      SLR2=(ELV(I+NY-1)-ELV(I+NY-2))/2./SH                               000980
      SLAV=(SLL+SLL1)/2.                                                 000990
      IF(SLAV.LT.0.0)SLAV=0.0                                            001000
      SRAV=(SLR+SLR1)/2.                                                 001010
      IF(SRAV.LT.0.0) SRAV=0.0                                           001020
      SQR=SLAV**0.5+ SRAV**0.5                                           001030
      QL(I)=QL(I)+QT(I)*((SLAV**0.5)/SQR)                                001040
      QR(I)=QR(I)+QT(I)*((SRAV**0.5)/SQR)                                001050
      CALL        RDISTB(I,CODE(I))                                      001060
      GO TO 901                                                          001070
  920 QL(I)=0                                                            001080
      QR(I)=0                                                            001090
      GO TO 901                                                          001100
  921 QL(I)=0                                                            001110
      QR(I)=QR(I)+QT(I)                                                  001120
      CALL        RDISTB(I,CODE(I))                                      001130
      GO TO 901                                                          001140
  922 QR(I)=0                                                            001150
      QL(I)=QL(I)+QT(I)                                                  001160
      CALL        RDISTB(I,CODE(I))                                      001170
      GO TO 901                                                          001180
  930 QT(I)=QT(I)+QT(I+1)+DQ                                             001190
      SLR=(ELV(I  )-ELV(I+NY-1  ))/2.0/SH                                001200
      SLL=0.0                                                            001210
      QL(I)=0.0                                                          001220
      IF(SLR.GT.0) GO TO 932                                             001230
      QR(I)=0.0                                                          001240
      GO TO 901                                                          001250
  932 QR(I)=QR(I)+QT(I)                                                  001260
      CALL        RDISTB(I,CODE(I))                                      001270
      GO TO 901                                                          001280
  940 QT(I)=QT(I)+QT(I+1)+DQ                                             001290
      SLL=(ELV(I  )-ELV(I-NY-1  ))/2.0/SH                                001300
      SLR=0.0                                                            001310
      QR(I)=0.0                                                          001320
      IF(SLL.GT.0) GO TO 942                                             001330
      QL(I)=0.0                                                          001340
      GO TO 901                                                          001350
  942 QL(I)=QL(I)+QT(I)                                                  001360
      CALL        RDISTB(I,CODE(I))                                      001370
  901 CONTINUE                                                           001380
      IF(NT.NE.1) RETURN                                                 001390
C     WRITE(6,990)(I,X(I),Y(I),CODE(I),QR(I),QL(I),QT(I),  I=1,NMAX)     001400
  990 FORMAT(2X,I5,6F20.8)                                               001410
      RETURN                                                             001420
      END                                                                001430
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      SUBROUTINE RDISTB(I,CKODE)                                          P00010
C     ****************************************************************    P00020
C     THIS SUBPROGRAM CHECKS THE EXISTANCE OF NEGATIVE SIDE SLOPES        P00030
C     RESULT FROM HUMPS DEPRESSED BY FAILURE MECHANISM. THE PROGRAM       P00040
C     THEN REDISTRIBUTES THE QUANTITY OF WATER AMONG NODAL POINTS. THIS   P00050
C     PROCESS IS REPEATED BEFORE EVERY TIME INTERVAL.                     P00060
C     ****************************************************************    P00070
C                                                                         P00080
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                  P00090
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                   P00100
      COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                          P00110
      COMMON/PONDC/KPND(2000),NAJ(2000),DH(2000)                          P00120
      COMMON/QFLOW/QT(2000),QL(2000),QR(2000)                             P00130
      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),    P00140
     #  HMP6(500)                                                         P00150
      COMMON NT                                                           P00160
      IF(Y(I).EQ.0.0) GO TO 100                                           P00170
      IF(CKODE-1.0)  100,200,300                                          P00180
  200 AELV=(ELV(I)+ELV(I-1))/2.                                           P00190
      SO=(ELV(I)-ELV(I-1))/2./SH                                          P00200
      CALL IDHMP(NY,I,IDL,IDR,IDC)                                        P00210
      IF(X(I).EQ.0.0) GO TO 210                                           P00220
      IF(X(I).EQ.X(NMAX)) GO TO 220                                       P00230
      S1=(HMP4(IDL)-AELV)/SH/3.**0.5                                      P00240
      S2=(HMP1(IDR)-AELV)/SH/3.**0.5                                      P00250
   20 FORMAT(/,'  SLOPES :',I5,3F20.6)                                    P00260
      AS1=ABS(S1)                                                         P00270
      AS2=ABS(S2)                                                         P00280
      IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 100                               P00290
      IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 215                               P00300
      IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 225                               P00310
    1 CONTINUE                                                            P00320
      NK=I-2*NY                                                           P00330
      NV=I                                                                P00340
      F=0.5                                                               P00350
      KK=1                                                                P00360
      HHH=(ELV(NK)+ELV(NK-1))/2.                                          P00370
      IF(HHH.GT.HMP1(IDL)) QT(NV)=0.0                                     P00380
      GO TO 2000                                                          P00390
  211 NK=I+2*NY                                                           P00400
      NV=I                                                                P00410
      F=0.5                                                               P00420
      KK=2                                                                P00430
      GO TO 2000                                                          P00440
  215 IF(SO.GE.AS1) GO TO 290                                             P00450
      NK=I-2*NY                                                           P00460
      NV=I                                                                P00470
      F=1.0                                                               P00480
      KK=2                                                                P00490
      HHH=(ELV(NK)+ELV(NK-1))/2.                                          P00500
      IF(HHH.GT.HMP1(IDL)) QT(NV)=0.0                                     P00510
      GO TO 2000                                                          P00520
  225 IF(SO.GE.AS2) GO TO 290                                             P00530
      NK=I+2*NY                                                           P00540
      NV=I                                                                P00550
      F=1.0                                                               P00560
      KK=2                                                                P00570
      GO TO 2000                                                          P00580
  210 S2=(HMP1(IDR)-AELV)/SH/3.**0.5                                      P00590
      AS2=ABS(S2)                                                         P00600
      IF(S2.LE.0.0) GO TO 225                                             P00610
      GO TO 100                                                           P00620
  220 S1=(HMP4(IDL)-AELV)/SH/3.**0.5                                      P00630
      AS1=ABS(S1)                                                         P00640
      IF(S1.LE.0.0) GO TO 215                                             P00650
      GO TO 100                                                           P00660
 2000 QT(NK)=QT(NK)+F*QT(NV)                                              P00670
      IF(KK.EQ.1) GO TO 211                                               P00680
      QT(NV)=0.0                                                          P00690
  290 IF(SO.LE.0.0)  GO TO 100                                            P00700
      NAJ(I)=NAJ(I)-1                                                     P00710
      NAJ(I-1)=NAJ(I-1)-1                                                 P00720
      GO TO 100                                                           P00730
  300 CALL IDHMP(NY,I,IDL,IDR,IDC)                                        P00740
   10 FORMAT(/,I5,3F20.8,/)                                               P00750
      IF(X(I).EQ.0.0) GO TO 400                                           P00760
      AELV=(ELV(I)+ELV(I-NY-1))/2.                                        P00770
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      SOL=(ELV(I)-ELV(I-NY-1))/2./SH                                    P00780
      S2=(HMP2(IDC)-AELV)/SH/3.**0.5                                    P00790
      IF(Y(I).EQ.Y(NY)) HMP5(IDL)=HMP2(IDC)                             P00800
      S1=(HMP5(IDL)-AELV)/SH/3.**0.5                                    P00810
      AS1=ABS(S1)                                                       P00820
      AS2=ABS(S2)                                                       P00830
      IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 400                             P00840
      IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 315                             P00850
      IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 325                             P00860
      NK=I-NY+2                                                         P00870
      NV=I                                                              P00880
      IF(Y(NV).GE.Y(NY-1)) NK=NMAX+5                                    P00890
      IF(X(NV).EQ.X(NY+1)) NK=NMAX+5                                    P00900
      F=0 .5                                                            P00910
      KK=1                                                              P00920
      HHH=(ELV(NK)+ELV(NK-NY-1))/2.                                     P00930
      IF(HHH.GT.HMP2(IDL)) QL(NV)=0.0                                   P00940
      GO TO 3000                                                        P00950
311   NK=I+NY-2                                                         P00960
      NV=I                                                              P00970
      F=0.5                                                             P00980
      KK=2                                                              P00990
      GO TO 3000                                                        P01000
315   IF(SOL.GE.AS1) GO TO 390                                          P01010
      NK=I-NY+2                                                         P01020
      NV=I                                                              P01030
      IF(Y(NV).GE.Y(NY-1)) NK=NMAX+5                                    P01040
      IF(X(NV).EQ.X(NY+1)) NK=NMAX+5                                    P01050
      F=1.0                                                             P01060
      KK=2                                                              P01070
      HHH=(ELV(NK)+ELV(NK-NY-1))/2.                                     P01080
      IF(HHH.GT.HMP2(IDL)) QL(NV)=0.0                                   P01090
      GO TO 3000                                                        P01100
325   IF(SOL.GE.AS2) GO TO 390                                          P01110
      NK=I+NY-2                                                         P01120
      NV=I                                                              P01130
      F=1.0                                                             P01140
      KK=2                                                              P01150
3000  QL(NK)=QL(NK)+F*QL(NV)                                            P01160
      QL(NV)=0.0                                                        P01170
      IF(KK.EQ.1) GO TO 311                                             P01180
390   IF(SOL.LE.0.0) GO TO 400                                          P01190
      NAJ(I)=NAJ(I)-1                                                   P01200
      NAJ(I-NY-1)=NAJ(I-NY-1)-1                                         P01210
400   IF(X(I).EQ.X(NMAX)) GO TO 100                                     P01220
      IF(Y(I).EQ.Y(NY)) HMP6(IDR)=HMP3(IDC)                             P01230
      AELV=(ELV(I)+ELV(I+NY-1))/2.                                      P01240
      SOR=(ELV(I)-ELV(I+NY-1))/2./SH                                    P01250
      S1=(HMP3(IDC)-AELV)/SH/3.**0.5                                    P01260
      S2=(HMP6(IDR)-AELV)/SH/3.**0.5                                    P01270
      AS1=ABS(S1)                                                       P01280
      AS2=ABS(S2)                                                       P01290
      IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 100                             P01300
      IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 415                             P01310
      IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 425                             P01320
      NK=I-NY-2                                                         P01330
      NV=I                                                              P01340
      IF(Y(NV).GE.Y(NY-1)) NK=NMAX+5                                    P01350
      IF(X(NV).EQ.X(NY+1)) NK=NMAX+5                                    P01360
      F=0.5                                                             P01370
      KK=1                                                              P01380
      GO TO 4000                                                        P01390
411   NK=I+NY+2                                                         P01400
      NV=I                                                              P01410
      IF(Y(NV).GE.Y(NY-1)) NK=NMAX+5                                    P01420
      IF(X(NV).EQ.X(NY+1)) NK=NMAX+5                                    P01430
      F=0.5                                                             P01440
      KK=2                                                              P01450
      HHH=(ELV(NK)+ELV(NK+NY-1))/2.                                     P01460
      IF(HHH.GT.HMP3(IDR)) QR(NV)=0.0                                   P01470
      GO TO 4000                                                        P01480
415   IF(SOR.GE.AS1) GO TO 490                                          P01490
      NK=I-NY-2                                                         P01500
      NV=I                                                              P01510
      F=1.0                                                             P01520
      KK=2                                                              P01530
      GO TO 4000                                                        P01540
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 425  IF(SOR.GE.AS2) GO TO 490                                          P01550
      NK=I+NY+2                                                         P01560
      NV=I                                                              P01570
      IF(Y(NV).GE.Y(NY-1)) NK=NMAX+5                                    P01580
      IF(X(NV).EQ.X(NY+1)) NK=NMAX+5                                    P01590
      F=1.0                                                             P01600
      KK=2                                                              P01610
      HHH=(ELV(NK)+ELV(NK+NY-1))/2.                                     P01620
      IF(HHH.GT.HMP3(IDR)) QR(NV)=0.0                                   P01630
 4000 QR(NK)=QR(NK)+F*QR(NV)                                            P01640
      QR(NV)=0.0                                                        P01650
      IF(KK.EQ.1) GO TO 411                                             P01660
 490  IF(SOR.LE.0.0) GO TO 100                                          P01670
      NAJ(I)=NAJ(I)-1                                                   P01680
      NAJ(I+NY-1)=NAJ(I+NY-1)-1                                         P01690
  100 CONTINUE                                                          P01700
 500  FORMAT(/,120('_'),/)                                              P01710
  990 FORMAT(2X,I5,6F20.8)                                              P01720
      RETURN                                                            P01730
      END                                                               P01740
      SUBROUTINE SFAILR(SLIMIT,SSTART)                                  Q00010
C     ****************************************************************  Q00020
C     THIS SUBPROGRAM CHECKS THE STABILITY OF SIDESLOPES OF ALL RILL    Q00030
C     SEGMENTS BEFORE EVERY TIME INTERVAL.                              Q00040
C     SLIMIT=THE UPPER LIMIT A SIDESLOPE CAN REACH BEFORE FAILURE       Q00050
C     SSTART= THE STARTING VALUE OF THE SIDESLOPE AFTER FAILURE         Q00060
C     DSDT= THE VOLUME OF THE SOIL CHUNK SEPARATED DUE TO FAILURE       Q00070
C     NOTE: AT THE PRESENT STAGE DSDT IS NOT ADDED TO THE AMOUNT OF     Q00080
C     SOIL ERODED . I. E. DSDT=0.                                       Q00090
C     ****************************************************************  Q00100
C                                                                       Q00110
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                Q00120
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 Q00130
      COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                        Q00140
      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),  Q00150
     #  HMP6(500)                                                       Q00160
      COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000)                       Q00170
      COMMON NT                                                         Q00180
  16  FORMAT(I5,2F20.6,/)                                               Q00190
  10  FORMAT(I5,3F10.5)                                                 Q00200
  15  FORMAT(I5,F10.5)                                                  Q00210
1000  FORMAT(3I10,2F10.5,//)                                            Q00220
      BETA=ATAN(SSTART)                                                 Q00230
      PHI=ATAN(SLIMIT)-BETA                                             Q00240
      DY=SH*(SLIMIT-SSTART)*3.**0.5*COS(BETA)                           Q00250
      DSDT=SH*SH*SH*(SLIMIT-SSTART)                                     Q00260
      DSDT=0.0                                                          Q00270
      DO 100 J=1,NY                                                     Q00280
      K=NY+(1-J)                                                        Q00290
      DO 100 I=K,NMAX,NY                                                Q00300
      IF(Y(I).EQ.0.0) GO TO 100                                         Q00310
      IF(CODE(I)-1) 100,200,300                                         Q00320
 200  AELV=(ELV(I)+ELV(I-1))/2.                                         Q00330
      CALL IDHMP(NY,I,IDL,IDR,IDC)                                      Q00340
      IF(X(I).EQ.0.0) GO TO 210                                         Q00350
      IF(X(I).EQ.X(NMAX)) GO TO 220                                     Q00360
      S1=(HMP4(IDL)-AELV)/SH/(3.**0.5)                                  Q00370
      S2=(HMP1(IDR)-AELV)/SH/(3.**0.5)                                  Q00380
  230 IF(S1.LT.SLIMIT) GO TO 205                                        Q00390
      HMP4(IDL)=HMP4(IDL)-(S1-SSTART)*SH*3.**0.5                        Q00400
      SDT(I)=SDT(I)+DSDT                                                Q00410
      TIRE(I)=TIRE(I)+DSDT                                              Q00420
 205  IF(S2.LT.SLIMIT) GO TO 100                                        Q00430
      HMP1(IDR)=HMP1(IDR)-(S2-SSTART)*SH*3.**0.5                        Q00440
      SDT(I)=SDT(I)+DSDT                                                Q00450
      TIRE(I)=TIRE(I)+DSDT                                              Q00460
      GO TO 100                                                         Q00470
 210  S2=(HMP1(IDR)-AELV)/SH/3.**0.5                                    Q00480
      S1=S2                                                             Q00490
      GO TO 230                                                         Q00500
 220  S1=(HMP4(IDL)-AELV)/SH/3.**0.5                                    Q00510
      S2=S1                                                             Q00520
      GO TO 230                                                         Q00530
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  300  CALL IDHMP(NY,I,IDL,IDR,IDC)                                      Q00540
 3000 FORMAT(4I8,2F12.8,//)                                             Q00550
      IF(X(I).EQ.0.0) GO TO 330                                         Q00560
      AELV=(ELV(I)+ELV(I-NY-1))/2.                                      Q00570
      S2=(HMP2(IDC)-AELV)/SH/3.**0.5                                    Q00580
      HP5=HMP5(IDL)                                                     Q00590
      IF(Y(I).EQ.Y(NY)) HP5=HMP2(IDC)                                   Q00600
      S1=(HP5-AELV)/SH/3.**0.5                                          Q00610
      IF(S1.LT.SLIMIT) GO TO 310                                        Q00620
      IF(Y(I).EQ.Y(NY)) GO TO 305                                       Q00630
      HMP5(IDL)=HMP5(IDL)-(S1-SSTART)*SH*3.**0.5                        Q00640
  305 CONTINUE                                                          Q00650
      SDT(I-NY-1)=SDT(I-NY-1)+DSDT                                      Q00660
      TIRE(I-NY-1)=TIRE(I-NY-1)+DSDT                                    Q00670
  310 IF(S2.LT.SLIMIT) GO TO 330                                        Q00680
      HMP2(IDC)=HMP2(IDC)-(S2-SSTART)*SH*3.**0.5                        Q00690
      SDT(I-NY-1)=SDT(I-NY-1)+DSDT                                      Q00700
      TIRE(I-NY-1)=TIRE(I-NY-1)+DSDT                                    Q00710
  330 IF(X(I).EQ.X(NMAX)) GO TO 100                                     Q00720
      HP6=HMP6(IDR)                                                     Q00730
      IF(Y(I).EQ.Y(NY)) HP6=HMP3(IDC)                                   Q00740
      AELV=(ELV(I)+ELV(I+NY-1))/2.                                      Q00750
      S1=(HMP3(IDC)-AELV)/SH/3.**0.5                                    Q00760
      S2=(HP6-AELV)/SH/3.**0.5                                          Q00770
      IF(S1.LT.SLIMIT) GO TO 340                                        Q00780
      HMP3(IDC)=HMP3(IDC)-(S1-SSTART)*SH*3.**0.5                        Q00790
      SDT(I+NY-1)=SDT(I+NY-1)+DSDT                                      Q00800
      TIRE(I+NY-1)=TIRE(I+NY-1)+DSDT                                    Q00810
  340 IF(S2.LT.SLIMIT) GO TO 100                                        Q00820
      IF(Y(I).EQ.Y(NY)) GO TO 350                                       Q00830
      HMP6(IDR)=HMP6(IDR)-(S2-SSTART)*SH*3.**0.5                        Q00840
  350 CONTINUE                                                          Q00850
      SDT(I+NY-1)=SDT(I+NY-1)+DSDT                                      Q00860
      TIRE(I+NY-1)=TIRE(I+NY-1)+DSDT                                    Q00870
  100 CONTINUE                                                          Q00880
      RETURN                                                            Q00890
      END                                                               Q00900
      SUBROUTINE POND                                                   R00010
C     ****************************************************************  R00020
C     THIS SUBPROGRAM IDENTIFIES NODAL POINTS WHICH ARE THE UPSTREAM    R00030
C     POINTS OF RILL SEGMENTS OF NEGATIVE SLOPE,(UPWARD), AND AT WHICH  R00040
C     PONDING OCCURS                                                    R00050
C     ****************************************************************  R00060
C                                                                       R00070
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                R00080
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 R00090
      COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)                        R00100
      COMMON NT                                                         R00110
      DO 10 I=1,NMAX                                                    R00120
      KPND(I)=0                                                         R00130
      IF(Y(I).EQ.0.0) GO TO 10                                          R00140
      IF(CODE(I)-1.0) 10,20,30                                          R00150
C                                                                       R00160
C     FOR NODAL POINTS WITH CODE=1                                      R00170
C                                                                       R00180
C     KPND(I)=0 IMPLIES NO PONDING                                      R00190
C     KPND(I)=11 IMPLIES PONDING                                        R00200
   20 DZ=ELV(I  )-ELV(I-1  )                                            R00210
      IF(DZ.GT.0.0) GO TO 10                                            R00220
      KPND(I)=11                                                        R00230
      GO TO 10                                                          R00240
C                                                                       R00250
C     FOR NODAL POINTS WITH CODE=2                                      R00260
C                                                                       R00270
C     KPND(I)=0  IMPLIES NO PONDING                                     R00280
C     KPND(I)=11IMPLIES TOTAL PONDING                                   R00290
C     KPND(I)=1  IMPLIES PARTIAL PONDING ,(LEFT BRANCH ONLY).           R00300
C     KPND(I)=2  IMPLIES PARTIAL PONDING ,(RIGHT BRANCH ONLY).          R00310
   30 IF(X(I).EQ.0.0) GO TO 35                                          R00320
      DZL=ELV(I  )-ELV(I-NY-1  )                                        R00330
      IF(X(I).EQ.X(NMAX)) GO TO 40                                      R00340
      DZR=ELV(I  )-ELV(I+NY-1  )                                        R00350
      IF(DZL.LE.0.0 .AND.DZR.LE.0.0) GO TO 45                           R00360
      IF(DZL.GT.0.0.AND.DZR.GT.0.0) GO TO 10                            R00370
      IF(DZL.GT.0.0.AND.DZR.LE.0.0) GO TO 50                            R00380
      KPND(I)=1                                                         R00390
      GO TO 10                                                          R00400
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   50  KPND(I)=2                                                          R00410
       GO TO 10                                                           R00420
   45  KPND(I)=11                                                         R00430
       GO TO 10                                                           R00440
   35  DZR=ELV(I   )-ELV(I+NY-1   )                                       R00450
       IF(DZR.GT.0.0) GO TO 10                                            R00460
       GO TO 45                                                           R00470
   40  DZL=ELV(I   )-ELV(I-NY-1   )                                       R00480
       IF(DZL.GT.0.0) GO TO 10                                            R00490
       GO TO 45                                                           R00500
   10  CONTINUE                                                           R00510
       RETURN                                                             R00520
       END                                                                R00530
       SUBROUTINE ACJNT                                                   S00010
C      ******************************************************************* S00020
C      THIS SUBPROGRAM COMPUTES THE NUMBER OF RILL SEGMENTS AT EACH       S00030
C      NODAL POINT                                                        S00040
C      ******************************************************************* S00050
C                                                                         S00060
       COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                 S00070
       COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                  S00080
       COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)                         S00090
       COMMON NT                                                          S00100
       DO 10 I=1,NMAX                                                     S00110
       IF(CODE(I)-1) 10,20,30                                             S00120
    20 IF(Y(I).EQ.Y(NY)) GO TO 15                                         S00130
       IF(X(I).EQ.0.0.OR.X(I).EQ.X(NMAX)) GO TO 25                        S00140
       NAJ(I)=3                                                           S00150
       GO TO 10                                                           S00160
   15  NAJ(I)=1                                                           S00170
       GO TO 10                                                           S00180
   25  NAJ(I)=2                                                           S00190
       GO TO 10                                                           S00200
   30  IF(Y(I).EQ.0.0) GO TO 15                                           S00210
       IF(Y(I).EQ.Y(NY)) GO TO 35                                         S00220
       IF(X(I).EQ.X(NMAX).OR.X(I).EQ.0.0) GO TO 25                        S00230
       NAJ(I)=3                                                           S00240
       GO TO 10                                                           S00250
   35  IF(X(I).NE.0.0.AND.X(I).NE.X(NMAX)) GO TO 25                       S00260
       GO TO 15                                                           S00270
    10 CONTINUE                                                           S00280
C      WRITE(6,5)(I,X(I),Y(I),          CODE(I),KPND(I),NAJ(I),I=1,NMAX) S00290
    5  FORMAT(I5,3F20.5,2I5)                                              S00300
       RETURN                                                             S00310
       END                                                                S00320
       SUBROUTINE CSEC(SL,Q,S1,S2,SO,H,B,C1)                              T00010
C      ******************************************************************* T00020
C      THIS SUBPROGRAM COMPUTES DEPTH AND BREADTH OF THE FLOW AT ANY      T00030
C      NODAL POINT. COMPUTATIONS ARE BASED ON M A N N I N G 'S FORMULA.   T00040
C      FLOW MEAN VELOCITY AND VELOCITY HEAD ARE ALSO COMPUTED HERE.       T00050
C      ******************************************************************* T00060
C                                                                         T00070
       COMMON /PROP/GAMA,RO,G,SG,RN                                       T00080
       COMMON NT                                                          T00090
       THETA1=ATAN(S1)                                                    T00100
       THETA2=ATAN(S2)                                                    T00110
       C1=1/S1+1/S2                                                       T00120
       C2=1/SIN(THETA1)+1/SIN(THETA2)                                     T00130
       C3=C1/C2                                                           T00140
       CC=2.**(5./3.)*RN/C1/C3**(2./3.)                                   T00150
       H=(CC/SO**0.5)**0.375*Q**0.375                                     T00160
C                                                                         T00170
C      CHECK FOR OVERFLOW                                                 T00180
       HM1=S1*SL*(3.**0.5)                                                T00190
       HM2=S2*SL*(3.**0.5)                                                T00200
       IF(HM1.LT.HM2) GO TO 1710                                          T00210
       HMAX=HM2                                                           T00220
       GO TO 1720                                                         T00230
 1710  HMAX=HM1                                                           T00240
 1720  IF(H.GT.HMAX)   H=HMAX                                             T00250
       B=H*C1                                                             T00260
       RH=0.5*H*C3                                                        T00270
       V=1./RN *(RH**(2./3.)) * SO**0.5                                   T00280
       EG=V*V/2./G                                                        T00290
C      WRITE(6,10) V,EG                                                   T00300
   10  FORMAT(//,10X,'VELOCITY=',F12.8,10X,'ENERGY=',F12.8,/)             T00310
       RETURN                                                             T00320
       END                                                                T00330
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      SUBROUTINE RERSN(SO,SL,SH,RCH,C1,H1,H2,EX,B1,B2,TI,TE,DE)          U00010
C     ************************************************************      U00020
C     THIS SUBPROGRAM COMPUTES THE AMOUNT OF MATERIAL ERODED FROM       U00030
C     A RILL SEGMENT (RILL EROSION).                                    U00040
C     COMPUTATIONS ARE BASED ON THE ASSUMPTION OF UNIFORM RILL FLOW.    U00050
C     K A L I N S K E 'S BED LOAD FORMULA IS USED AS THE SEDIMENT       U00060
C     PICK-UP CRITERION.                                                U00070
C     DE = THE REDUCTION IN BED ELEVATION DUE TO EROSION.               U00080
C     ************************************************************      U00090
C                                                                       U00100
      REAL*4 TE,DE                                                      U00110
      COMMON /PROP/GAMA,RO,G,SG,RN                                      U00120
      COMMON NT                                                         U00130
      TAU1=GAMA*C1*SO*H1*H1/2.                                          U00140
      TAU2=GAMA*C1*SO*H2*H2/2.                                          U00150
      XL=2.*SL                                                          U00160
      E= RCH*(TAU2-TAU1)/XL*((TAU2+TAU1)/2.)**EX*60                     U00170
C ... E= EROSION RATE IN CUBIC METERS/METER LENGTH/MINUTE               U00180
      TE=E*XL*TI                                                        U00190
C ... TE IS DEDUCTED UNIFORMLY ALONG THE RILL LENGTH                    U00200
      KF=2                                                              U00210
      WD=2.*SL*3.**0.5                                                  U00220
   30 BB=(B1+B2)/2.*KF                                                  U00230
      IF(BB.GT.0.0) GO TO 40                                            U00240
      DE=0.0                                                            U00250
      RETURN                                                            U00260
   40 IF(BB.GT.WD) GO TO 35                                             U00270
      DE=2.*TE/SH/BB                                                    U00280
      GO TO 50                                                          U00290
   35 KF=KF-1                                                           U00300
      IF(KF.LT.1) KF=1                                                  U00310
      GO TO 30                                                          U00320
   50 RETURN                                                            U00330
      END                                                               U00340
      SUBROUTINE HERSN(QQ,SL,EM,EH,HCH,B1,B2,H1,H2,EX,TI,TEH)           V00010
C     ************************************************************      V00020
C     THIS SUBPROGRAM COMPUTES THE AMOUNT OF MATERIAL ERODED FROM SIDE  V00030
C     HUMPS OF ANY RILL SEGMENT (INTERRILL AREAS).                      V00040
C     COMPUTATIONS ARE BASED ON THE ASSUMPTION OF UNIFORM SHEET FLOW    V00050
C     OVER AN EQUIVALENT RECTANGULAR AREA.                              V00060
C     K A L I N S K E 'S BED LOAD FORMULA IS USED AS THE SEDIMENT       V00070
C     PICK-UP CRITERION.                                                V00080
C     ************************************************************      V00090
C                                                                       V00100
      REAL*4 EM,EH,TEH                                                  V00110
      COMMON /PROP/GAMA,RO,G,SG,RN                                      V00120
      COMMON NT                                                         V00130
      ZRO=1/(10.**20.)                                                  V00140
      IF(B1.GE.1000..AND.B2.GE.1000.) GO TO 30                          V00150
      XH=SL*(3.**0.5)                                                   V00160
      HH=EH-EM                                                          V00170
      SO=(EH-EM)/XH                                                     V00180
      THETA=ATAN(SO)                                                    V00190
      ZL=HH/SIN(THETA)                                                  V00200
      HAV=(H1+H2)/2.                                                    V00210
      RL=ZL-HAV/SIN(THETA)                                              V00220
C     IF WATER OVERFLOWS ON THIS SIDE ,THEN N  EROSION WILL TAKE        V00230
C     PLACE ON IT.                                                      V00240
      IF(RL.LE.0.0) GO TO 100                                           V00250
      YL=2.*RL*SL/ZL                                                    V00260
      XL=RL/2.                                                          V00270
   50 Q=QQ*XL                                                           V00280
      Y=(RN*Q/SO**0.5)**0.6                                             V00290
      TAU=GAMA*Y*SO                                                     V00300
      E=HCH*TAU/XL*(TAU/2.)**EX*60.                                     V00310
      TEH=E*XL*YL*TI                                                    V00320
   10 FORMAT(7F15.8)                                                    V00330
      RETURN                                                            V00340
  100 TEH=0.0                                                           V00350
      RETURN                                                            V00360
   30 SO=ABS(H1)                                                        V00370
      IF(SO.LE.ZRO) RETURN                                              V00380
      XL=0.5*SL                                                         V00390
      YL=2.*SL                                                          V00400
      GO TO 50                                                          V00410
      END                                                               V00420
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      SUBROUTINE ERSN1(I,QTT,HCH,RCH,EX,TI)                              W00010
C     ***************************************************************    W00020
C     THIS SUBPROGRAM PERFORMS EROSION COMPUTATIONS ON RILL SEGMENTS     W00030
C     WITH UP-STREAM POINT HAVING CODE=1 .                               W00040
C     S1 = SLOPE OF THE LEFT SIDE OF THE RILL SIDE WALLS                 W00050
C     S2 = SLOPE OF THE RIGHT SIDE OF THE RILL SIDE WALLS                W00060
C     Q1 = FLOW RATE AT UPSTREAM END OF THE RILL SEGMENT                 W00070
C     Q2 = FLOW RATE AT DOWNSTREAM END OF THE RILL SEGMENT               W00080
C     SDT(I),TRE(I),TIRE(I) ARE DEFINED IN MAIN PGM                      W00090
C     DH(I) = CHANGE IN ELEVATION OF I AT THE END OF A TIME INTERVAL     W00100
C     ***************************************************************    W00110
C                                                                        W00120
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                 W00130
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                  W00140
      COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                         W00150
      COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)                         W00160
      COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000)                        W00170
      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),   W00180
     #  HMP6(500)                                                        W00190
      COMMON /PROP/GAMA,RO,G,SG,RN                                       W00200
      COMMON NT                                                          W00210
      ZRO=1.0/(10.0**20.)                                                W00220
      KODE=1                                                             W00230
      DE=0.0                                                             W00240
      TE=0.0                                                             W00250
      E1=ELV(I)                                                          W00260
 1015 E2=ELV(I-1)                                                        W00270
      AELV=(E1+E2)/2.                                                    W00280
C                                                                        W00290
C ... IDENTIFY HUMPS ON LEFT AND ON RIGHT                                W00300
      CALL IDHMP(NY,I,IDL,IDR,NDUMY)                                     W00310
      IF(X(I).EQ.0) GO TO 1020                                           W00320
      IF(X(I).EQ.X(NMAX)) GO TO    1030                                  W00330
C                                                                        W00340
C ... COMPUTATIONS FOR RILL SEGMENTS NOT ON THE BOUNDARIES               W00350
C     ***************************************************              W00360
      S1=(HMP4(IDL)-AELV)/SH/3.**0.5                                     W00370
      S2=(HMP1(IDR)-AELV)/SH/3.**0.5                                     W00380
      SO=(E1-E2)/2./SH                                                   W00390
      IF(SO.LE.ZRO) GO TO 1065                                           W00400
   10 CONTINUE                                                           W00410
      DQ=2.*QQ*SL*SL*(3.**0.5)                                           W00420
      Q2=QTT                                                             W00430
      Q1=Q2-DQ                                                           W00440
      IF(Q1.LT.0.0) Q1=0.0                                               W00450
      IF(Q2.LT.0.0) Q2=0.0                                               W00460
C                                                                        W00470
C ... CHECK FOR NEGATIVE SIDE SLOPES                                     W00480
      IF(S1.LE.ZRO.OR.S2.LE.ZRO) GO TO 1025                              W00490
   11 CONTINUE                                                           W00500
C                                                                        W00510
C ... COMPUTE DEPTH AND WIDTH OF THE FLOW AT THE TWO END POINTS          W00520
      CALL        CSEC(SL,Q1,S1,S2,SO,H1,B1,C1)                          W00530
      CALL        CSEC(SL,Q2,S1,S2,SO,H2,B2,C1)                          W00540
C                                                                        W00550
C ... COMPUTE EROSION FROM NEIGHBORING HUMPS                             W00560
      CALL        HERSN(QQ,SL,AELV,HMP4(IDL),HCH,B1,B2,H1,H2,EX,TI,TEHL) W00570
      CALL        HERSN(QQ,SL,AELV,HMP1(IDR),HCH,B1,B2,H1,H2,EX,TI,TEHR) W00580
C                                                                        W00590
C ... CHECK FOR PONDING . IF IT OCCURS, DEPOSIT SEDIMENT LOAD AT         W00600
C     DESIGNATED POINTS(SEE NEXT COMMENT STATEMENT).                     W00610
      IF(KPND(I-1).NE.11) GO TO 1017                                     W00620
      TDP=SDT(I)+TEHL+TEHR                                               W00630
C                                                                        W00640
C ... SEDIMENT LOAD AT I IS DEPOSITED ON RILL SEGMENTS OF SIX MESH       W00650
C     "BACK STEPS" (BETWEEN I-1 AND I+3) .                               W00660
C     DD1,....,DD5 ARE DEPTHS OF MATERIAL DEPOSITED AT DIFFERENT         W00670
C     BACK STEPS.                                                        W00680
   29 CONTINUE                                                           W00690
      KF=2                                                               W00700
      WD=WL                                                              W00710
   30 BB=(B1+B2)/2.*KF                                                   W00720
      IF(BB.GT.WD) GO TO 35                                              W00730
      DD1=2.5/29.*2.*TDP/SH/BB                                           W00740
      GO TO 40                                                           W00750
   35 KF=KF-1                                                            W00760
      IF(KF.LT.1) KF=1                                                   W00770
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      GO TO 30                                                          W00780
   40 DD2=0.8*DD1                                                       W00790
      DD3=0.6 *DD1                                                      W00800
      DD4=0.4* DD1                                                      W00810
      DD5=0.2* DD1                                                      W00820
      DH(I-1)=DH(I-1)-1.*DD1                                            W00830
      DH(I)=DH(I)-1.*DD2                                                W00840
      IF(Y(I+NY+1).LT.Y(I)) GO TO 200                                   W00850
      IF((I+NY+1).GT.NMAX) GO TO 20                                     W00860
      DH(I+NY+1)=DH(I+NY+1)-1.*DD3                                      W00870
   20 IF((I-NY+1).LE.0) GO TO 21                                        W00880
      DH(I-NY+1)=DH(I-NY+1)-1.*DD3                                      W00890
   21 IF(Y(I+NY+2).LT.Y(I+NY+1)) GO TO 200                              W00900
      IF((I+NY+2).GT.NMAX) GO TO 22                                     W00910
      DH(I+NY+2)=DH(I+NY+2)-1.*DD4                                      W00920
   22 IF((I-NY+2).LE.0) GO TO 23                                        W00930
      DH(I-NY+2)=DH(I-NY+2)-1.*DD4                                      W00940
   23 IF(Y(I+3).LT.Y(I)) GO TO 200                                      W00950
      DH(I+3)=DH(I+3)-1.*DD5                                            W00960
      IF((I+2*NY+3).GT.NMAX) GO TO 24                                   W00970
      DH(I+2*NY+3)=DH(I+2*NY+3)-1.*DD5                                  W00980
   24 IF((I-2*NY+3).LE.0) GO TO 200                                     W00990
      DH(I-2*NY+3)=DH(I-2*NY+3)-1.*DD5                                  W01000
  200 CONTINUE                                                          W01010
      SDT(I-1)=0.0                                                      W01020
      TRE(I-1)=0.0                                                      W01030
      TIRE(I-1)=0.0                                                     W01040
 1021 RETURN                                                            W01050
 1017 CONTINUE                                                          W01060
C                                                                       W01070
C ... COMPUTE RILL EROSION                                              W01080
      CALL       RERSN(SO,SL,SH,RCH,C1,H1,H2,EX,B1,B2,TI,TE,DE)       W01090
C                                                                       W01100
C ... COMPUTE CHANGE IN ELEVATION OF TWO END POINTS                     W01110
      DH(I)=DH(I)+DE/(NAJ(I)*1.)                                        W01120
      DH(I-1)=DH(I-1)+DE/(NAJ(I-1)*1.)                                  W01130
C                                                                       W01140
C ... COMPUTE SEDIMENT DISCHARGE AT NODAL POINTS                        W01150
      SDT(I-1)=SDT(I-1)+SDT(I)+TE+TEHL+TEHR                             W01160
      TRE(I-1)=TRE(I-1)+TRE(I)+TE                                       W01170
      TIRE(I-1)=TIRE(I-1)+TIRE(I)+TEHR+TEHL                             W01180
      RETURN                                                            W01190
C                                                                       W01200
C ... COMPUTATIONS FOR RILL SEGMENTS WITH NEGATIVE SIDE SLOPE(S).       W01210
C     NO RILL EROSION IN THIS CASE.                                     W01220
 1025 B1=1000.                                                          W01230
      B2=1000.                                                          W01240
C ... LARGE VALUES OF B1 AND B2(1000) IS FOR IDENTIFICATION ONLY        W01250
      CALL HERSN(QQ,SL,AELV,HMP4(IDL),HCH,B1,B2,S1,H2,EX,TI,TE1)        W01260
      CALL HERSN(QQ,SL,AELV,HMP1(IDR),HCH,B1,B2,S2,H2,EX,TI,TE2)        W01270
C                                                                       W01280
C ... REDISTRIBUTE THE SEDIMENT LOAD WHEN EITHER SIDE SLOPES IS -VE.    W01290
      CALL SNEGTV(I,S1,S2,TE1,TE2,KODE, T , R  ,  H  ,NBRNCH)           W01300
      RETURN                                                            W01310
C                                                                       W01320
C ... COMPUTATIONS FOR RILL SEGMENTS ON THE BOUNDARIES                  W01330
C     ****************************************                          W01340
C ... RILL SEGMENTSON THE BOUNDARY ARE ASSUMED TO HAVE SYMMETRICAL      W01350
C     SIDE SLOPES                                                       W01360
C     THE SAME SEQUENCE OF COMPUTATION IS FOLLOWED                      W01370
 1020 S=(HMP1(IDR)-AELV)/SH/3.**0.5                                     W01380
      EH=HMP1(IDR)                                                      W01390
      GO TO 1040                                                        W01400
 1030 S=(HMP4(IDL)-AELV)/SH/3.**0.5                                     W01410
      S1=S                                                              W01420
      S2=S                                                              W01430
      EH=HMP4(IDL)                                                      W01440
 1040 SO=(ELV(I  )-ELV(I-1  ))/2./SH                                    W01450
      IF(SO.LE.ZRO) GO TO 1065                                          W01460
   12 CONTINUE                                                          W01470
      AELV=(ELV(I  )+ELV(I-1  ))/2.                                     W01480
      DQ=2.*QQ*SL*SL*(3.**0.5)                                          W01490
      Q2=QTT                                                            W01500
      Q1=Q2-DQ                                                          W01510
      IF(Q1.LT.0.0) Q1=0.0                                              W01520
      IF(Q2.LT.0.0) Q2=0.0                                              W01530
      IF(S.LE.ZRO) GO TO 1035                                           W01540
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   13  CONTINUE                                                          W01550
       CALL        CSEC(SL,Q1,S,S,SO,H1,B1,C1)                           W01560
       CALL        CSEC(SL,Q2,S ,S ,SO,H2,B2,C1)                         W01570
       CALL        HERSN(QQ,SL,AELV,EH,HCH,B1,B2,H1,H2,EX,TI,TEH)        W01580
       IF(KPND(I-1).NE.11) GO TO 1016                                    W01590
       TDP=SDT(I)+TEH                                                    W01600
       GO TO 29                                                          W01610
  1016 CONTINUE                                                          W01620
       CALL        RERSN(SO,SL,SH,RCH,C1,H1,H2,EX,B1,B2,TI,TE,DE)        W01630
       DH(I)=DH(I)+DE/(NAJ(I)*1.)                                        W01640
       DH(I-1)=DH(I-1)+DE/(NAJ(I-1)*1.)                                  W01650
       SDT(I-1)=SDT(I-1)+SDT(I)+TE+TEH                                   W01660
       TRE(I-1)=TRE(I-1)+TRE(I)+TE                                       W01670
       TIRE(I-1)=TIRE(I-1)+TIRE(I)+TEH                                   W01680
       RETURN                                                            W01690
  1035 B1=1000.                                                          W01700
       B2=1000.                                                          W01710
       CALL HERSN(QQ,SL,AELV,EH,HCH,B1,B2,S,H2,EX,TI,TE)                 W01720
       CALL SNEGTV(I,S ,S ,TE ,TE ,KODE, T , R  ,  H  ,NBRNCH)           W01730
       RETURN                                                            W01740
  1065 CONTINUE                                                          W01750
C      WRITE(6,1070)I,SO                                                 W01760
  1070 FORMAT(/,10X,'PONDING OCCURED AT PT.  ',I5 ,5X,'SO=',F12.8)       W01770
       RETURN                                                            W01780
       END                                                               X00010
       SUBROUTINE ERSN2(I,QLL,QRR,HCH,RCH,EX,TI)                         X00020
C      ***************************************************************** X00030
C      THIS SUBPROGRAM PERFORMS EROSION COMPUTATIONS ON RILL SEGMENTS    X00040
C      WITH UP-STREAM POINT HAVING CODE=2 .                              X00050
C                                                                        X00060
C      S1 = SLOPE OF THE LEFT SIDE OF THE RILL SIDE WALLS                X00070
C      S2 = SLOPE OF THE RIGHT SIDE OF THE RILL SIDE WALLS               X00080
C      Q1 = FLOW RATE AT UPSTREAM END OF THE RILL SEGMENT                X00090
C      Q2 = FLOW RATE AT DOWNSTREAM END OF THE RILL SEGMENT              X00100
C      SDT(I),TRE(I),TIRE(I) ARE DEFINED IN MAIN PGM                     X00110
C      DH(I) = CHANGE IN ELEVATION OF I AT THE END OF A TIME INTERVAL    X00120
C      ***************************************************************** X00130
C                                                                        X00140
       COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                X00150
       COMMON/PONDG/KPND(2000),NAJ(2000),DH(2000)                        X00160
       COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                        X00170
       COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 X00180
       COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000)                       X00190
       COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),  X00200
      #  HMP6(500)                                                       X00210
       COMMON /PROP/GAMA,RO,G,SC,RN                                      X00220
       COMMON NT                                                         X00230
       ZRO=1.0/(10.0**20.)                                               X00240
       KODE=2                                                            X00250
       DE=0.0                                                            X00260
       TE=0.0                                                            X00270
       DQ=2.*QQ*SL*SL*(3.**0.5)                                          X00280
C                                                                        X00290
C ...  IDENTIFY THE THREE NEIGHBORING HUMPS                              X00300
       CALL   IDHMP(NY,I,IDL,IDR,IDC)                                    X00310
       SOL=(ELV(I  )-(ELV(I-NY-1  )))/2./SH                              X00320
       SOR=(ELV(I  )-(ELV(I+NY-1  )))/2./SH                              X00330
       IF(X(I).EQ.0) GO TO 1110                                          X00340
       IF(X(I).EQ.X(NMAX)) GO TO 1120                                    X00350
       IF(SOL.LE.ZRO.AND.SOR.LE.ZRO) GO TO 1170                          X00360
       IF(SOL.LE.ZRO.AND.SOR.GT.ZRO) GO TO 1110                          X00370
       IF(SOL.GT.ZRO.AND.SOR.LT.ZRO) GO TO 1120                          X00380
  201  CONTINUE                                                          X00390
C                                                                        X00400
C ...  SEDIMENT LOAD IS DEVIDED BETWEEN THE TWO BRANCHES ACCORDING TO    X00410
C      THE RELATIVE MAGNITUDES OF BED SLOPES RAISED TO THE POWER OF 1.25 X00420
       SOL2=(ELV(I-NY-1)-ELV(I-NY-2))/2./SH                              X00430
       SOR2=(ELV(I-NY-1)-ELV(I-NY-2))/2./SH                              X00440
       SAVL=(SOL+SOL2)/2.                                                X00450
       IF(SAVL.LT.0.0) SAVL=0.0                                          X00460
       SAVR=(SOR+SOR2)/2.                                                X00470
       IF(SAVR.LT.0.0) SAVR=0.0                                          X00480
       SS=SAVL**1.25+SAVR**1.25                                          X00490
       IF(SS.LE.0.0) GO TO 210                                           X00500
       STL=SDT(I)*(SAVL**1.25)/SS                                        X00510
       RENL=TRE(I)*(SAVL**1.25)/SS                                       X00520
       HRENL=TIRE(I)*(SAVL**1.25)/SS                                     X00530
       GO TO 220                                                         X00540
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  210 STL=0.5*SDT(I)                                                    X00540
      RENL=0.5*TRE(I)                                                   X00550
      HRENL=0.5*TIRE(I)                                                 X00560
  220 CONTINUE                                                          X00570
C                                                                       X00580
C ... COMPUTATIONS FOR RILL SEGMENT ON THE LEFT                         X00590
C     ****************************************                          X00600
C                                                                       X00610
      K=1                                                               X00620
      GO TO 1140                                                        X00630
 1120 K=2                                                               X00640
      IF(SOL.LE.0.0) GO TO 1170                                         X00650
      STL=SDT(I)                                                        X00660
      RENL=TRE(I)                                                       X00670
      HRENL=TIRE(I)                                                     X00680
 1140 SO=SOL                                                            X00690
      AELV=(ELV(I   )+ELV(I-NY-1   ))/2.                                X00700
      S2=(HMP2(IDC)-AELV)/SH/3.**0.5                                    X00710
      HP5=HMP5(IDL)                                                     X00720
C                                                                       X00730
C ... RILL SEGMENTSON THE BOUNDARY ARE ASSUMED TO HAVE SYMMETRICAL      X00740
C     SIDE SLOPES                                                       X00750
      IF(Y(I).EQ.Y(NY)) HP5=HMP2(IDC)                                   X00760
      S1=(HP5-AELV)/SH/3.**0.5                                          X00770
      Q1=QLL                                                            X00780
      IF(Q1.LT.0.0) Q1=0.0                                              X00790
      Q2=Q1+DQ                                                          X00800
C                                                                       X00810
C ... CHECK FOR NEGATIVE SIDE SLOPES                                    X00820
      IF(S1.LE.ZRO.OR.S2.LE.ZRO) GO TO 1145                             X00830
  202 CONTINUE                                                          X00840
C                                                                       X00850
C ... COMPUTE DEPTH AND WIDTH OF THE FLOW AT THE TWO END POINTS         X00860
      CALL        CSEC(SL,Q1,S1,S2,SO,H1,B1,C1)                         X00870
      CALL        CSEC(SL,Q2,S1,S2,SO,H2,B2,C1)                         X00880
C                                                                       X00890
C ... COMPUTE EROSION FROM NEIGHBORING HUMPS                            X00900
      CALL        HERSN(QQ,SL,AELV,HP5       ,HCH,B1,B2,H1,H2,EX,TI,TEHL)  X00910
      CALL        HERSN(QQ,SL,AELV,HMP2(IDC),HCH,B1,B2,H1,H2,EX,TI,TEHLC)  X00920
C                                                                       X00930
C ... CHECK FOR PONDING . IF IT OCCURS, DEPOSIT SEDIMENT LOAD AT        X00940
C     DESIGNATED POINTS(SEE NEXT COMMENT STATEMENT).                    X00950
      IF(KPND(I-NY-1).NE.11) GO TO 1115                                 X00960
C                                                                       X00970
C ... SEDIMENT LOAD AT I IS DEPOSITED ON RILL SEGMENTS OF SIX MESH      X00980
C     "BACK STEPS"                                                      X00990
      TDP=STL+TEHL+TEHLC                                                X01000
      KF=2                                                              X01010
      WD=WL                                                             X01020
   30 BB=(B1+B2)/2.*KF                                                  X01030
      IF(BB.GT.WD) GO TO 35                                             X01040
C                                                                       X01050
C     DD1,.....,DD5 ARE DEPTHS OF MATERIAL DEPOSITED AT DIFFERENT       X01060
C     BACK STEPS.                                                       X01070
      DD1=2.5/35.*2.*TDP/SH/BB                                          X01080
      GO TO 40                                                          X01090
   35 KF=KF-1                                                           X01100
      IF(KF.LT.1) KF=1                                                  X01110
      GO TO 30                                                          X01120
   40 DD2=0.8*DD1                                                       X01130
      DD3=0.6*DD1                                                       X01140
      DD4=0.4*DD1                                                       X01150
      DD5=0.2*DD1                                                       X01160
      DH(I-NY-1)=DH(I-NY-1)-1.*DD1                                      X01170
      DH(I)=DH(I)-1.*DD2                                                X01180
      IF((I-2*NY).LE.0) GO TO 10                                        X01190
      DH(I-2*NY)=DH(I-2*NY)-1.*DD2                                      X01200
   10 IF(Y(I+1).LT.Y(I)) GO TO 100                                      X01210
      DH(I+1)=DH(I+1)-1.*DD3                                            X01220
      IF((I-2*NY+1).LE.0) GO TO 11                                      X01230
      DH(I-2*NY+1)=DH(I-2*NY+1)-1.*DD3                                  X01240
   11 IF(Y(I+NY+2).LT.Y(I)) GO TO 100                                   X01250
      IF((I+NY+2).GT.NMAX) GO TO 12                                     X01260
      DH(I+NY+2)=DH(I+NY+2)-1.*DD4                                      X01270
   12 DH(I-NY+2)=DH(I-NY+2)-1.*DD4                                      X01280
      IF((I-3*NY+2).LE.0) GO TO 13                                      X01290
      DH(I-3*NY+2)=DH(I-3*NY+2)-1.*DD4                                  X01300
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   13  IF(Y(I+NY+3).LT.Y(I)) GO TO 100                                    X01310
       IF((I+NY+3).GT.NMAX) GO TO 14                                      X01320
       DH(I+NY+3)=DH(I+NY+3)-1.*DD5                                       X01330
   14  IF((I-NY+3).LE.0) GO TO 15                                         X01340
       DH(I-NY+3)=DH(I-NY+3)-1.*DD5                                       X01350
   15  IF((I-3*NY+3).LE.0) GO TO 100                                      X01360
       DH(I-3*NY+3)=DH(I-3*NY+3)-1.*DD5                                   X01370
  100  CONTINUE                                                           X01380
 1021  RETURN                                                             X01390
 1115  CONTINUE                                                           X01400
C                                                                         X01410
C ... COMPUTE RILL EROSION                                                X01420
      CALL        RERSN(SO,SL,SH,RCH,C1,H1,H2,EX,B1,B2,TI,TE,DE)          X01430
C                                                                         X01440
C ... COMPUTE CHANGE IN ELEVATION OF TWO END POINTS                       X01450
      DH(I)=DH(I)+DE/(1.*NAJ(I))                                          X01460
      DH(I-NY-1)=DH(I-NY-1)+DE/(1.*NAJ(I-NY-1))                           X01470
C                                                                         X01480
C ... COMPUTE SEDIMENT DISCHARGE AT NODAL POINTS                          X01490
      SDT(I-NY-1)=SDT(I-NY-1)+STL+TE+TEHL+TEHLC                           X01500
      TRE(I-NY-1)=TRE(I-NY-1)+RENL+TE                                     X01510
      TIRE(I-NY-1)=TIRE(I-NY-1)+HRENL+TEHL+TEHLC                          X01520
C                                                                         X01530
C ... CHECK FOR -VE. SIDE SLOPES                                          X01540
 1145 IF(S1.GT.0.0.AND.S2.GT.0.0) GO TO 1150                              X01550
      NBRNCH=1                                                            X01560
      B1=1000.                                                            X01570
      B2=1000.                                                            X01580
C     NOTE: THE LARGE VALUES OF B1, AND B2 (1000.) ARE USED ONLY AS FLAGS X01590
C                                                                         X01600
C ... COMPUTATIONS FOR RILL SEGMENTS WITH NEGATIVE SIDE SLOPE(S).         X01610
C     NO RILL EROSION IN THIS CASE.                                       X01620
      CALL HERSN(QQ,SL,DMY1,DMY2,HCH,B1,B2,S2,H2,EX,TI,TE2)               X01630
      CALL HERSN(QQ,SL,DMY1,DMY2,HCH,B1,B2,S1,H2,EX,TI,TE1)               X01640
      KODE=2                                                              X01650
C                                                                         X01660
C ... REDISTRIBUTE THE SEDIMENT LOAD WHEN EITHER SIDE SLOPES IS -VE.      X01670
      CALL SNEGTV(I,S1,S2,TE1,TE2,KODE,STL,RENL,HRENL,NBRNCH)             X01680
 1150 IF(K.EQ.1) GO TO 1160                                               X01690
      RETURN                                                              X01700
C                                                                         X01710
C ... COMPUTATIONS FOR RILL SEGMENT ON THE RIGHT                          X01720
C     ****************************************                            X01730
C                                                                         X01740
C     THE SAME SEQUENCE OF COMPUTATIONS IS FOLLOWED                       X01750
 1110 IF(SOR.LE.0) GO TO 1170                                             X01760
      STL=0                                                               X01770
      RENL=0.0                                                            X01780
      HRENL=0.0                                                           X01790
 1160 STR=SDT(I)-STL                                                      X01800
      RENR=TRE(I)-RENL                                                    X01810
      HRENR=TIRE(I)-HRENL                                                 X01820
      SO=SOR                                                              X01830
      AELV=(ELV(I   )+ELV(I+NY-1   ))/2.                                  X01840
      S1=(HMP3(IDC)-AELV)/SH/3.**0.5                                      X01850
      HP6=HMP6(IDR)                                                       X01860
      IF(Y(I).EQ.Y(NY)) HP6=HMP3(IDC)                                     X01870
      S2=(HP6-AELV)/SH/3.**0.5                                            X01880
      Q1=QRR                                                              X01890
      IF(Q1.LT.0.0) Q1=0.0                                                X01900
      Q2=Q1+DQ                                                            X01910
      IF(S1.LE.ZRO.OR.S2.LE.ZRO) GO TO 1155                               X01920
  203 CONTINUE                                                            X01930
      CALL        CSEC(SL,Q1,S1,S2,SO,H1,B1,C1)                           X01940
      CALL        CSEC(SL,Q2,S1,S2,SO,H2,B2,C1)                           X01950
      CALL        HERSN(QQ,SL,AELV,HP6       ,HCH,B1,B2,H1,H2,EX,TI,TEHR) X01960
      CALL        HERSN(QQ,SL,AELV,HMP3(IDC),HCH,B1,B2,H1,H2,EX,TI,TEHRC) X01970
      IF(KPND(I+NY-1).NE.11) GO TO 1116                                   X01980
      TDP=STL+TEHR+TEHRC                                                  X01990
      KF=2                                                                X02000
      WD=WL                                                               X02010
   60 BB=(B1+B2)/2.*KF                                                    X02020
      IF(BB.GT.WD) GO TO 65                                               X02030
      DD1=2.5/35.*2.*TDP/SH/BB                                            X02040
      GO TO 70                                                            X02050
   65 KF=KF-1                                                             X02060
      IF(KF.LT.1) KF=1                                                    X02070
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      GO TO 60                                                          X02080
   70 DD2=0.8*DD1                                                       X02090
      DD3=0.6*DD1                                                       X02100
      DD4=0.4*DD1                                                       X02110
      DD5=0.2*DD1                                                       X02120
      DH(I+NY-1)=DH(I+NY-1)-1.*DD1                                      X02130
      DH(I)=DH(I)-1.*DD2                                                X02140
      IF((I+2*NY).GT.NMAX) GO TO 20                                     X02150
      DH(I+2*NY)=DH(I+2*NY)-1.*DD2                                      X02160
   20 IF(Y(I+1).LT.Y(I)) GO TO 200                                      X02170
      DH(I+1)=DH(I+1)-1.*DD3                                            X02180
      DH(I+2*NY+1)=DH(I+2*NY+1)-1.*DD3                                  X02190
      IF(Y(I+NY+2).LT.Y(I)) GO TO 200                                   X02200
      IF((I+NY+2).GT.NMAX) GO TO 21                                     X02210
      DH(I+NY+2)=DH(I+NY+2)-1.*DD4                                      X02220
   21 IF((I+3*NY+2).GT.NMAX) GO TO 22                                   X02230
      DH(I+3*NY+2)=DH(I+3*NY+2)-1.*DD4                                  X02240
   22 IF((I-NY+2).LT.0) GO TO 23                                        X02250
      DH(I-NY+2)=DH(I-NY+2)-1.*DD4                                      X02260
   23 IF(Y(I+3*NY+3).LE.Y(I)) GO TO 200                                 X02270
      IF((I+3*NY+3).GT.NMAX) GO TO 24                                   X02280
      DH(I+3*NY+3)=DH(I+3*NY+3)-1.*DD5                                  X02290
   24 IF((I+NY+3).GT.NMAX) GO TO 25                                     X02300
      DH(I+NY+3)=DH(I+NY+3)-1.*DD5                                      X02310
   25 IF((I-NY+3).LE.0) GO TO 200                                       X02320
      DH(I-NY+3)=DH(I-NY+3)-1.*DD5                                      X02330
  200 CONTINUE                                                          X02340
      SDT(I+NY-1)=0.0                                                   X02350
      TRE(I+NY-1)=0.0                                                   X02360
      TIRE(I+NY-1)=0.0                                                  X02370
 1023 RETURN                                                            X02380
 1116 CONTINUE                                                          X02390
      CALL        RERSN(SO,SL,SH,RCH,C1,H1,H2,EX,B1,B2,TI,TE,DE)        X02400
      DH(I)=DH(I)+DE/(1.*NAJ(I))                                        X02410
      DH(I+NY-1)=DH(I+NY-1)+DE/(1.*NAJ(I+NY-1))                         X02420
      SDT(I+NY-1)=SDT(I+NY-1)+STR+TE+TEHR+TEHRC                         X02430
      TRE(I+NY-1)=TRE(I+NY-1)+RENR+TE                                   X02440
      TIRE(I+NY-1)=TIRE(I+NY-1)+HRENR+TEHR+TEHRC                        X02450
      RETURN                                                            X02460
 1155 IF(S1.GT.ZRO.AND.S2.GT.ZRO)RETURN                                 X02470
  204 CONTINUE                                                          X02480
      NBRNCH=2                                                          X02490
      B1=1000.                                                          X02500
      B2=1000.                                                          X02510
      CALL HERSN(QQ,SL,DMY1,DMY2,HCH,B1,B2,S1,H2,EX,TI,TE1)             X02520
      CALL HERSN(QQ,SL,DMY1,DMY2,HCH,B1,B2,S2,H2,EX,TI,TE2)             X02530
      KODE=2                                                            X02540
      CALL SNEGTV(I,S1,S2,TE1,TE2,KODE,STR,RENR,HRENR,NBRNCH)           X02550
      RETURN                                                            X02560
 1170 CONTINUE                                                          X02570
C     WRITE(6,1175) I,SOL,SOR                                           X02580
 1175 FORMAT(/,10X,'PONDING OCCURED AT PT.  ',I5,5X,'SOL=',F12.8,       X02590
     #  5X,'SOR=',F12.8)                                               X02600
      RETURN                                                            X02610
      END                                                               X02620
      SUBROUTINE SNEGTV(I,S1,S2,TE1,TE2,KODE,T,R,H,NBRNCH)              Y00010
C     ****************************************************************  Y00020
C     THIS SUBPROGRAM MODEFIES THE EROSION COMPUTATIONS WHEN EITHER     Y00030
C     SIDESLOPES OF A RILL SEGMENT IS NEGATIVE.                         Y00040
C                                                                       Y00050
C     NV= LOCATION OF SEDIMENT LOAD BEFORE MODEFICATION                 Y00060
C     NK= LOCATION OF SEDIMENT LOAD AFTER  MODEFICATION                 Y00070
C     TE1= VOLUME OF SOIL ERODED FROM LEFT SIDESLOPE                    Y00080
C     TE1= VOLUME OF SOIL ERODED FROM RIGHT SIDESLOPE                   Y00090
C     ****************************************************************  Y00100
C                                                                       Y00110
      COMMON/MESH/NX,NY,NMAX,SL,SH,WL,QQ                                Y00120
      COMMON/HHMPP/HHMP(500),XHMP(500),YHMP(500)                        Y00130
      COMMON/SLOPES/HMP1(500),HMP2(500),HMP3(500),HMP4(500),HMP5(500),  Y00140
        HMP6(500)                                                       Y00150
      COMMON/NODES/X(2000),Y(2000),CODE(2000),ELV(2000)                 Y00160
      COMMON/SDMNT/SDT(2000),TRE(2000),TIRE(2000)                       Y00170
      COMMON NT                                                         Y00180
      FORMAT(/,'  POINT # ',I3,5F20.8,/)                                Y00190
      E1=TE1                                                            Y00200
      E2=TE2                                                            Y00210
      CALL IDHMP(NY,I,IDL,IDR,IDC)                                      Y00220
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      GO TO (100,200),KODE                                              Y00230
100   SO=(ELV(I)-ELV(I-1))/2./SH                                        Y00240
      IF(X(I).EQ.0.0) GO TO 120                                         Y00250
      IF(X(I).EQ.X(NMAX)) GO TO 110                                     Y00260
      IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 110                             Y00270
      IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 120                             Y00280
      NK=I-2*NY-1                                                       Y00290
      NV=I                                                              Y00300
      IF(X(NV).LE.X(NY+1)) NK=NMAX+5                                    Y00310
      F=0.5                                                             Y00320
      KK=1                                                              Y00330
      E2=0.0                                                            Y00340
      HHH=(ELV(NK)+ELV(NK+1))/2.                                        Y00350
      IF(HHH.GT.HMP1(IDL))  GO TO 105                                   Y00360
      GO TO 1000                                                        Y00370
105   F=0.0                                                             Y00380
      E1=0.0                                                            Y00390
      E2=0.0                                                            Y00400
      GO TO 1000                                                        Y00410
 111  NK=I+2*NY-1                                                       Y00420
      NV=I                                                              Y00430
      IF(X(NV).GE.X(NMAX-NY)) NK=NMAX+5                                 Y00440
      F=0.5                                                             Y00450
      KK=2                                                              Y00460
      E2=TE2                                                            Y00470
      E1=0.0                                                            Y00480
      HHH=(ELV(NK)+ELV(NK+1))/2.                                        Y00490
      IF(HHH.GT.HMP4(IDR))  GO TO 105                                   Y00500
      GO TO 1000                                                        Y00510
 110  NK=I-2*NY-1                                                       Y00520
      NV=I                                                              Y00530
      F=1.0                                                             Y00540
      KK=2                                                              Y00550
      IF(X(NV).LE.X(NY+1)) NK=NMAX+5                                    Y00560
      AS1=ABS(S1)                                                       Y00570
      IF(SO.GE.AS1) GO TO 117                                           Y00580
      HHH=(ELV(NK)+ELV(NK+1))/2.                                        Y00590
      IF(HHH.GT.HMP1(IDL))  GO TO 115                                   Y00600
      GO TO 1000                                                        Y00610
115   F=0.0                                                             Y00620
      E1=0.0                                                            Y00630
      E2=0.0                                                            Y00640
      GO TO 1000                                                        Y00650
117   F=0.0                                                             Y00660
      E=E2                                                              Y00670
      E2=0.0                                                            Y00680
      KK=3                                                              Y00690
      GO TO 1000                                                        Y00700
 120  NK=I+2*NY-1                                                       Y00710
      NV=I                                                              Y00720
      IF(X(NV).GE.X(NMAX-NY)) NK=NMAX+5                                 Y00730
      F=1.0                                                             Y00740
      KK=2                                                              Y00750
      HHH=(ELV(NK)+ELV(NK+1))/2.                                        Y00760
      IF(HHH.GT.HMP4(IDR))  GO TO 115                                   Y00770
      AS2=ABS(S2)                                                       Y00780
      IF(SO.GE.AS2) GO TO 127                                           Y00790
      GO TO 1000                                                        Y00800
127   F=0.0                                                             Y00810
      E=E1                                                              Y00820
      E1=0.0                                                            Y00830
      KK=3                                                              Y00840
      GO TO 1000                                                        Y00850
1000  SDT(NK)=SDT(NK)+F*SDT(NV)+E1+E2                                   Y00860
      TRE(NK)=TRE(NK)+F*TRE(NV)                                         Y00870
      TIRE(NK)=TIRE(NK)+F*TIRE(NV)+E1+E2                                Y00880
      IF(KK.EQ.1) GO TO 111                                             Y00890
      IF(KK.EQ.3) GO TO 1500                                            Y00900
      GO TO 1700                                                        Y00910
1500  SDT(NV-1)=SDT(NV-1)+SDT(NV)+E                                     Y00920
      TRE(NV-1)=TRE(NV-1)+TRE(NV)                                       Y00930
      TIRE(NV-1)=TIRE(NV-1)+TIRE(NV)+E                                  Y00940
1700  CONTINUE                                                          Y00950
      RETURN                                                            Y00960
200   CALL IDHMP(NY,I,IDL,IDR,IDC)                                      Y00970
      IF(NBRNCH.EQ.2) GO TO 300                                         Y00980
      IF(X(I).EQ.0.0) GO TO 300                                         Y00990
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      SOL=(ELV(I)-ELV(I-NY-1))/2./SH                                    Y01000
      AS1=ABS(S1)                                                       Y01010
      AS2=ABS(S2)                                                       Y01020
      IF (S1.LE.0.0.AND.S2.GT.0.0) GO TO 210                            Y01030
      IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 220                             Y01040
      NK=I-2*NY+1                                                       Y01050
      IF(Y(I).GE.Y(NY-1)) NK=NMAX+5                                     Y01060
      IF(X(I).EQ.X(NY+1)) NK=NMAX+5                                     Y01070
      F=0.5                                                             Y01080
      KK=1                                                              Y01090
      E2=0 0                                                            Y01100
      HHH=(ELV(NK)+ELV(NK+NY+1))/2.                                     Y01110
      IF(HHH.GT.HMP2(IDL))  GO TO 205                                   Y01120
      GO TO 2000                                                        Y01130
  205 F=0.0                                                             Y01140
      E1=0.0                                                            Y01150
      E2=0.0                                                            Y01160
      GO TO 2000                                                        Y01170
  211 NK=I-3                                                            Y01180
      IF(Y(I).EQ.Y(3)) NK=I+NY-2                                        Y01190
      F=0.5                                                             Y01200
      KK=2                                                              Y01210
      E2=TE2                                                            Y01220
      E1=0.0                                                            Y01230
      HHH=(ELV(NK)+ELV(NK+NY+1))/2.                                     Y01240
      IF(HHH.GT.HMP5(IDC))  GO TO 205                                   Y01250
      GO TO 2000                                                        Y01260
  210 NK=I-2*NY+1                                                       Y01270
      IF(Y(I).GE.Y(NY-1)) NK=NMAX+5                                     Y01280
      IF(X(I).EQ.X(NY+1)) NK=NMAX+5                                     Y01290
      F=1.0                                                             Y01300
      KK=2                                                              Y01310
      IF(SOL.GT.AS1) GO TO 217                                          Y01320
      HHH=(ELV(NK)+ELV(NK+NY+1))/2.                                     Y01330
      IF(HHH.GT.HMP2(IDL))  GO TO 205                                   Y01340
      GO TO 2000                                                        Y01350
  217 F=0.0                                                             Y01360
      E=E2                                                              Y01370
      E2=0.0                                                            Y01380
      KK=3                                                              Y01390
      GO TO 2000                                                        Y01400
  220 NK=I-3                                                            Y01410
      IF(Y(I).EQ.Y(3)) NK=I+NY-2                                        Y01420
      F=1.0                                                             Y01430
      KK=2                                                              Y01440
      IF(SOL.GT.AS2) GO TO 227                                          Y01450
      IF(X(I).EQ.X(NMAX)) GO TO 2000                                    Y01460
      HHH=(ELV(NK)+ELV(NK+NY+1))/2.                                     Y01470
      IF(HHH.GT.HMP5(IDC))  GO TO 205                                   Y01480
      GO TO 2000                                                        Y01490
  227 F=0.0                                                             Y01500
      E=E1                                                              Y01510
      E1=0.0                                                            Y01520
      KK=3                                                              Y01530
 2000 SDT(NK)=SDT(NK)+F* T +E1+E2                                       Y01540
      TRE(NK)=TRE(NK)+F*R                                               Y01550
      TIRE(NK)=TIRE(NK)+F*H+E1+E2                                       Y01560
      IF(KK.EQ.1) GO TO 211                                             Y01570
      IF(KK.EQ.3) GO TO 2500                                            Y01580
      GO TO 2700                                                        Y01590
 2500 SDT(I-NY-1)=SDT(I-NY-1)+T+E                                       Y01600
      TRE(I-NY-1)=TRE(I-NY-1)+R                                         Y01610
      TIRE(I-NY-1)=TIRE(I-NY-1)+H+E                                     Y01620
 2700 CONTINUE                                                          Y01630
    4 FORMAT(6F20.10,/)                                                 Y01640
      RETURN                                                            Y01650
  300 IF(X(I).EQ.X(NMAX))RETURN                                         Y01660
      SOR=(ELV(I)-ELV(I+NY-1))/2./SH                                    Y01670
      AS2=ABS(S2)                                                       Y01680
      AS1=ABS(S1)                                                       Y01690
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      IF(S1.GT.0.0.AND.S2.LE.0.0) GO TO 310                              Y01700
      IF(S1.LE.0.0.AND.S2.GT.0.0) GO TO 320                              Y01710
      NK=I+2*NY+1                                                        Y01720
      IF(Y(I).GE.Y(NY-1)) NK=NMAX+5                                      Y01730
      IF(X(I).EQ.X(NMAX-NY)) NK=NMAX+5                                   Y01740
      F=0.5                                                              Y01750
      KK=1                                                               Y01760
      E1=0.0                                                             Y01770
      HHH=(ELV(NK)+ELV(NK-NY+1))/2.                                      Y01780
      IF(HHH.GT.HMP3(IDR))  GO TO 305                                    Y01790
      GO TO 3000                                                         Y01800
305   F=0.0                                                              Y01810
      E1=0.0                                                             Y01820
      E2=0.0                                                             Y01830
      GO TO 3000                                                         Y01840
311   NK=I-3                                                             Y01850
      IF(Y(I).EQ.Y(3)) NK=I-NY-2                                         Y01860
      F=0.5                                                              Y01870
      KK=2                                                               Y01880
      E1=TE1                                                             Y01890
      E2=0.0                                                             Y01900
      HHH=(ELV(NK)+ELV(NK-NY+1))/2.                                      Y01910
      IF(HHH.GT.HMP6(IDC))  GO TO 305                                    Y01920
      GO TO 3000                                                         Y01930
 310  NK=I+2*NY+1                                                        Y01940
      IF(Y(I).GE.Y(NY-1)) NK=NMAX+5                                      Y01950
      IF(X(I).EQ.X(NMAX-NY)) NK=NMAX+5                                   Y01960
      F=1.0                                                              Y01970
      KK=2                                                               Y01980
      IF(SOR.GT.AS1) GO TO 317                                           Y01990
      HHH=(ELV(NK)+ELV(NK-NY+1)) /2.                                     Y02000
      IF(HHH.GT.HMP6(IDC))  GO TO 305                                    Y02010
      GO TO 3000                                                         Y02020
317   F=0.0                                                              Y02030
      E=E1                                                               Y02040
      E1=0.0                                                             Y02050
      KK=3                                                               Y02060
      GO TO 3000                                                         Y02070
320   NK=I-3                                                             Y02080
      IF(Y(I).EQ.Y(3)) NK=I-NY-2                                         Y02090
      F=1.0                                                              Y02100
      KK=2                                                               Y02110
      IF(SOR.GT.AS2) GO TO 327                                           Y02120
      IF(X(I).EQ.0.0) GO TO 3000                                         Y02130
      HHH=(ELV(NK)+ELV(NK-NY+1))/2.                                      Y02140
      IF(HHH.GT.HMP3(IDR))  GO TO 305                                    Y02150
      GO TO 3000                                                         Y02160
327   F=0.0                                                              Y02170
      E=E1                                                               Y02180
      E1=0.0                                                             Y02190
      KK=3                                                               Y02200
3000  SDT(NK)=SDT(NK)+F*T +E1+E2                                         Y02210
      TRE(NK)=TRE(NK)+F*R                                                Y02220
      TIRE(NK)=TIRE(NK)+F*H +E1+E2                                       Y02230
      IF(KK.EQ.1) GO TO 311                                              Y02240
      IF(KK.EQ.3) GO TO 3500                                             Y02250
      GO TO 3700                                                         Y02260
3500  SDT(I+NY-1)=SDT(I+NY-1)+T+E                                        Y02270
      TRE(I+NY-1)=TRE(I+NY-1)+R                                          Y02280
      TIRE(I+NY-1)=TIRE(I+NY-1)+H+E                                      Y02290
3700  CONTINUE                                                           Y02300
      RETURN                                                             Y02310
      END                                                                Y02320
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*                             *
*                             *
*       I N P U T  D A T A     *
*                             *
*                             *
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GROUP # 1 : SURFACE ROUGHNESS DATA
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****

NO. OF ELEVATION TRACES = 7

NO. OF POINTS PER TRACE = 100

SPACING = 2.00 CM

GROUP # 2 : PROBLEM PARAMETERS
****
****

SOIL PARTICLE DIAMETER =0.010 MLMTR

SOIL UNIT WEIGHT =16660. N/C. METER

SOIL SPECIFIC WEIGHT = 2.65

EXPONENT OF KALINSKE EQN. = 1.50

EQN. CONSTANT FOR RILLS =400.0

EQN. CONSTANT FOR HUMPS = 20.0

MANNING CONSTANT =0.040

GROUP # 3 : STORM AND SLOPE DATA
****
****

NO. OF MESH POINTS IN CROSS-DIRECTION = 65

NO. OF MESH POINTS IN LONGT-DIRECTION = 30

AVERAGE SLOPE = 20.0 DEGREES
= 36.41 PERCENT

RAINFALL INTENSITY = 50.0 MLMTR/HR

RUNOFF COEFFICIENT = 0.50

ANNUAL RAINFALL RATE =100.0 CNTMTR

EQUIVALENT YEARS OF RAIN = 0.25 YEARS

TIME INTERVAL = 10.0 MINUTES

TOTAL RAIN PERIOD = 5.00 HOURS

NO. OF RANDOM SURFACES = 1

FAILURE LIMIT FOR SIDE SLOPE = 1.40

STARTING LIMIT FOR SIDE SLOPE = 1.10

SPECTRAL ANALYSIS RESULTS

AVERAGE VALUES FOR ALL PROFILES

DEGREE	AN	BN	POWER	CONTR.	TOTAL	L (CM)
0	0.00	0.0	0.000	0.0	0.0	0.0
1	-3.73	5.08	26.373	0.1021	0.1021	198.00
2	5.14	3.01	28.660	0.1213	0.2234	99.00
3	-7.44	0.03	51.573	0.2030	0.4263	66.00
4	-1.39	2.23	6.368	0.0257	0.4520	49.50
5	0.08	1.61	4.803	0.0207	0.4727	39.60
6	-0.23	-0.25	5.473	0.0236	0.4963	33.00
7	-0.36	-0.94	3.866	0.0160	0.5123	28.29
8	0.36	1.16	3.864	0.0166	0.5290	24.75
9	-0.40	0.26	4.253	0.0187	0.5477	22.00
10	0.30	0.35	4.087	0.0156	0.5632	19.80
11	3.00	-2.23	10.397	0.0429	0.6061	18.00
12	-1.62	1.22	4.259	0.0171	0.6232	16.50
13	-0.30	0.51	4.770	0.0200	0.6432	15.23
14	1.00	0.25	3.735	0.0163	0.6595	14.14
15	0.55	1.08	3.243	0.0143	0.6737	13.20
16	0.72	-0.42	5.569	0.0217	0.6955	12.38
17	0.21	0.02	4.153	0.0173	0.7127	11.65
18	-1.22	-1.19	3.580	0.0147	0.7274	11.00
19	-0.55	-0.57	1.665	0.0066	0.7339	10.42
20	2.32	-0.62	3.820	0.0161	0.7501	9.90
21	0.24	-1.47	2.547	0.0102	0.7602	9.43
22	-0.46	0.80	2.371	0.0099	0.7702	9.00
23	1.96	-0.24	4.659	0.0179	0.7881	8.61
24	-1.05	-0.07	2.347	0.0094	0.7974	8.25
25	-0.73	0.83	5.703	0.0242	0.8217	7.92
26	0.18	0.37	1.808	0.0067	0.8283	7.62
27	0.07	0.11	2.606	0.0105	0.8388	7.33
28	0.98	-1.07	3.876	0.0160	0.8548	7.07
29	1.45	0.56	4.067	0.0167	0.8715	6.83
30	1.12	-0.42	1.495	0.0061	0.8776	6.60
31	0.36	0.02	0.577	0.0025	0.8801	6.39
32	1.12	-0.06	2.610	0.0105	0.8906	6.19
33	-0.22	0.12	1.397	0.0058	0.8964	6.00
34	0.50	-0.34	1.149	0.0044	0.9008	5.82
35	1.08	0.05	1.901	0.0074	0.9082	5.66
36	0.25	-0.47	1.384	0.0056	0.9137	5.50
37	0.59	-0.29	1.515	0.0061	0.9198	5.35
38	0.99	-0.94	2.421	0.0096	0.9294	5.21
39	1.17	0.19	2.047	0.0088	0.9382	5.08
40	0.52	0.51	3.057	0.0121	0.9504	4.95
41	0.23	0.33	1.819	0.0072	0.9576	4.83
42	0.75	0.78	1.401	0.0062	0.9638	4.71
43	0.00	0.25	1.030	0.0042	0.9680	4.60
44	0.48	-0.15	1.208	0.0047	0.9727	4.50
45	0.01	0.34	0.861	0.0037	0.9763	4.40
46	-0.16	0.76	1.333	0.0037	0.9820	4.30
47	0.57	0.07	1.139	0.0047	0.9867	4.21
48	0.01	-0.56	1.196	0.0048	0.9914	4 13
49	-0.22	-0.22	1.079	0.0043	0.9958	4.04
50	-0.17	0.0	0.993	0.0042	1.0000	3.96

AMPLITUDE OF REPRESENTATIVE WAVE= 3.740 MLMR

LENGTH OF REPRESENTATIVE WAVE = 18.000 CM

MEAN OF NORMAL DIST. = 4.719 MLMTR

STAND. DEVIATION OF NORMAL DIST.= 15.906 MLMTR

PLOT LENGTH= 2.286 METERS

PLOT WIDTH = 5.760 METERS

TEST AREA = 13.169 SQ. METERS

SHAPE FACTOR = 2.519

****

RANDOM SURFACE NO. 1

INTRVL #	RESULTS OF EACH INTERVAL TTL SDMT (N)	R/I RATIO	ERSN RATE (N/SM/HR)		CUMULATIVE RESULTS TTL SDMT (N)	R/I RATIO	ERSN RATE (N/SM/HR)
1	13.27	0.22	6.04	*	13.27	0.22	6.04
2	24 78	0.23	11.29	*	38.04	0.23	8.67
3	30.12	0.24	13.73	*	68.17	0.23	10.35
4	37.34	0.24	17.01	*	105.51	0.23	12.02
5	36.49	0.24	16.63	*	142.00	0.23	12.94
6	37.52	0.23	17.09	*	179.52	0.23	13.63
7	42.37	0.23	19.31	*	221.89	0.23	14.44
8	39.04	0.21	17.79	*	260.94	0.23	14.86
9	40.28	0.21	18.35	*	301.22	0.23	15.25
10	43.46	0.20	19.80	*	344.68	0.22	15.70
11	43.06	0.20	19.62	*	387.75	0.22	16.06
12	44.32	0.20	20.19	*	432.07	0.22	16.40
13	42.74	0.18	19.47	*	474.81	0.22	16.64
14	54.38	0.19	24.78	*	529.19	0.21	17.22
15	49.46	0.18	22.54	*	578.65	0.21	17.58
16	45.40	0.16	20.69	*	624.06	0.21	17.77
17	45.21	0.17	20.60	*	669.26	0.20	17.94
18	52.54	0.17	23.94	*	721.80	0.20	18.27
19	47.14	0.16	21.48	*	768.94	0.20	18.44
20	51.98	0.16	23.68	*	820.92	0.20	18.70
21	56.11	0.17	25.56	*	877.03	0.19	19.03
22	57.40	0.16	26.15	*	934.43	0.19	19.35
23	58.24	0.16	26.54	*	992.68	0.19	19.66
24	55.59	0.16	25.33	*	1048.27	0.19	19.90
25	62.91	0.16	28.66	*	1111.17	0.19	20.25
26	56.27	0.15	25.64	*	1167.45	0.18	20.46
27	60.49	0.15	27.56	*	1227.94	0.18	20.72
28	54.82	0.15	24.98	*	1282.76	0.18	20.87
29	64.35	0.15	29.32	*	1347.11	0.18	21.16
30	56.14	0.15	25.58	*	1403.25	0.18	21.31